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PRELIMINARY DESIGN STUDY OF ASTRONOMICAL DETECTOR COOLING SYSTEM

AiResearch Manufacturing Company
of California

November 17, 1976

(NASA-CR-151979) PRELIMINARY DESIGN STUDY
OF ASTRONOMICAL DETECTOR COOLING SYSTEM

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Prepared for

National Aeronautics and Space Administration
Ames Research Center
Moffett Field, California 94035

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FOREWORD

The Astronomical Detector Cooling System preliminary design study was performed under NASA Contract NAS2-8984, Amendment No. 1, by the AiResearch Manufacturing Company of California, a division of The Garrett Corporation. This work was sponsored by the Ames Research Center, Moffett Field, California, and administered under the direction of Mr. John Vorreiter, M/S 244-14.

This report was prepared by Mr. R. H. Norman, who was responsible for the analytical effort. Significant contributions to the system design and cost estimating were made by Mr. J. R. Wenker and Mr. S. V. Nicastro, under the Program direction of Mr. O. A. Buchmann.

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SECTION 1
INTRODUCTION AND SUMMARY

SECTION 1

INTRODUCTION AND SUMMARY

INTRODUCTION

This report presents the preliminary design of an astronomical detector cooling system for possible use in the NASA C-141 Airborne Infrared Observatory. The system was originally specified to consist of the following elements:

- Supercritical helium tank
- Flexible transfer line
- Joule-Thomson supply gas conditioner
- Joule-Thomson expander (JTX)
- Optical cavity dewar
- Optical cavity temperature controller
- Adjustable J-T discharge gas pressure controller
- Vacuum pump

Following an interface meeting on the C-141 it was decided that the flexible transfer line was not necessary, as the experiment could be mounted in the bent-Cassegrain telescope configuration.

Deliberate attempts were made to select low-cost components and make maximum use of commercially available hardware.

GENERAL REQUIREMENTS

The system is to be capable of cooling a detector heat load of up to 30 milliwatts at 2 K or less for 8 hours without recharging.

The cooling stability requirement is ± 0.05 K per second and ± 0.10 K per hour for the 30 milliwatt load at any preselected temperature between 2 K and 6 K.

The optical cavity dewar shall be capable of cooldown from 300 K within 2 hours. GFE instruments in the cavity shall be assumed to have a thermal mass equivalent to 100 grams of OFHC copper.

The structural requirement for all equipment specified that it shall be capable of sustaining an impact load of 9 g's without breaking loose of its supports.

All other general requirements are based on the "NASA C-141 Airborne Infrared Observatory Investigator's Handbook".

SUMMARY

The selected baseline system makes use of an Apollo Lunar Module (LM) supercritical helium tank, AiResearch P/N 900152-6-1, Serial No. 66-104, (Government property at NASA-JSC, Houston), which would undergo the modifications required to interface with a newly-designed optical cavity dewar. This tank was selected as a baseline because of its availability and well-known performance capabilities.

The optical cavity contains the Joule-Thomson expander (JTX), which provides the required cooling at 2 K. The JTX design is based on the two previous JTX's built under this contract. A separate report documents their development. The optical cavity dewar is designed with a vapor-cooled radiation shield around the JTX and cold plate. This shield is maintained at temperatures below 25 K by diverting most of the tank flow around the JTX, thus minimizing heat load on the JTX.

The interface between the tank and optical cavity is a rigid vacuum-jacketed line, making maximum use of the existing fill and delivery provisions of the LM tank.

All other elements of the system are selected from commercially available hardware. The total system weight is estimated to be 134 kg (295 lb), filled.

Preliminary system analysis indicates that two 8-hour missions can be flown within a 67-hour period on one liquid helium fill of 19.2 kg (42.4 lb), if a flow of 0.45 kg/hr (1.0 lb/hr) is withdrawn from the tank at a pressure of 10.2 atm (150 psia). To provide the hold time between flights the tank would be allowed to build up to a relief pressure of 13.6 atm (200 psia) and vent until the second flight begins, at which time a blowdown to 10.2 atm would provide sufficiently cold helium to the JTX inlet to begin another mission. The quantity of helium remaining after the second flight would be about 4.7 kg (10.4 lb). To accomplish a single 8-hour mission would require a charge of only 9.4 kg (20.8 lb), or an initial ullage volume of about 64 percent at 1.22 atm (18 psia).

Several other tankage options were investigated. The first alternate considered was the NASA-MSFC H₂/He tank, originally designed for the U.S. Air Force Manned Orbiting Laboratory (MOL) Program. One of the two tanks built is currently at AiResearch. This tank holds 70 kg (155 lb) of liquid helium and is too heavy to mount on the telescope flange. Its girth ring, as presently fabricated, will not meet the 9-g crash requirement; but it does have a JTX supply line specially built in.

The optimum-sized tank for an 8-hour mission, with 24 hr hold time, would hold about 5.5 kg (12 lb) of helium, assuming the same operating conditions as above, a transfer line temperature rise of only 1.0 K, and heat leak of 0.16 watt (0.55 Btu/hr). By comparison, the heat leak of the LM tank, a high performance tank for its size, is about 2.1 watts (7.2 Btu/hr). The availability of commercial dewars was investigated for the 8-hour mission problem statement. Such dewars are available and can be competitive with the LM tank for this application.

SECTION 2
SYSTEM DESCRIPTION

SECTION 2

SYSTEM DESCRIPTION

The Astronomical Detector Cooling System (ADCS) consists of three major components and a number of supporting components and controls. The three major components are:

- Supercritical helium tank
- Optical cavity dewar
- J-T expander (JTX)

The other components include: a transfer line, a tank and optical cavity support frame, JTX inlet and detector temperature controllers, a tank pressure control valve, a flow control valve and flowmeter, two warm-up heat exchanger coils, a JTX discharge pressure regulator valve, a tank pressure relief valve and burst disc, a tank pressure transducer and a tank temperature sensor.

A sketch of the system installation in the C-141 Airborne Infrared Observatory is shown in Figure 2-1. The system is outlined in Layout Drawing L197168*. Further detail of the LM helium tank is shown in Drawing 900155*. The optical cavity dewar design is shown in the Layout Drawing L197157*.

The supercritical helium tank, selected for the baseline, was designed to store up to 24.5 kg (54 lb) for use in the Lunar Module (LM) descent engine propellant pressurization system, and is a high-performance, superinsulated tank capable of withstanding internal pressure of 155 atm (2274 psia) at 78 K. It is constructed entirely of titanium alloy 5 Al 2.5 Sn ELI. Its maximum dry weight with external flight hardware was 52 kg (115 lb). The diameter of the outer shell is 83.8 cm (33.0 in), 87.4 cm (34.4 in) over the girth ring. One of these tanks, P/N 900152-6-1, S/N 66-104, is currently stored at NASA-JSC, Houston. It is provided with fill and vent quick disconnects, allowing for efficient helium servicing on-board the C-141 aircraft.

This tank demonstrated an average heat leak during a 131-hr pressure buildup test of 2.05 watts (7.0 Btu/hr) at 311 K ambient temperature in October 1966. The girth ring and mounting points are designed to withstand a 15-g acceleration load.

The optical cavity dewar consists of a copper cold plate, upon which the JTX is mounted, a copper vapor-cooled radiation shield (VCS), a compressed micro quartz felt pad support system, supply and discharge lines, temperature sensors and heaters, a VCS cooling line, and an infrared window. The cavity top, VCS top, JTX, and cold plate are all designed for ease of removal. The VCS support system is designed to remain in place (along with the VCS and its cooling tube), and consists of 3 equally-spaced pads around the cylindrical wall to absorb

*Included in Appendix A.

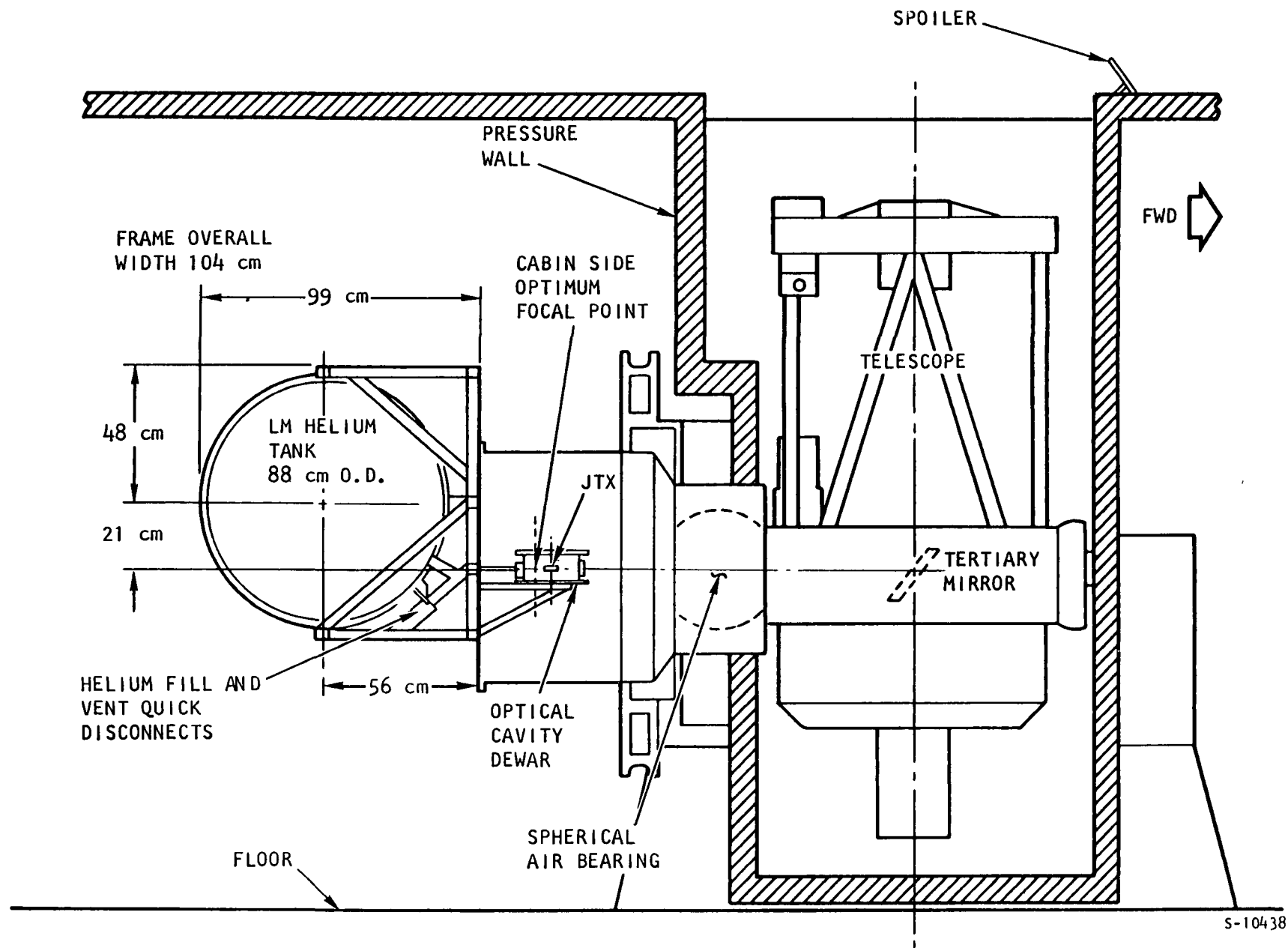


Figure 2-1. ADCS installation in C-141 Airborne Infrared Observatory

horizontal loads, and two sets of 3 each on the top and bottom of the VCS around the edge, to absorb vertical loads. (See detail on drawing L197157). This material is preloaded to about 4.8 atm (70 psig) to provide a natural frequency of about 136 Hz, well above the 3 Hz cutoff of the telescope vibration isolation system.

The Joule-Thomson expander and heat exchanger, JTX No. 3, is designed to provide the required cooling for: the load of 30 milliwatts; the heat leaks attributed to radiation from the infrared window; the conduction from the cold plate; and the conduction from the fluid lines and instrumentation leads. Radiation from the VCS is negligible because of its low operating temperature. This low VCS temperature, 15 to 25 K, is obtained by setting the vapor cooling flow rate at about 10 times the flow required by the JTX. The construction of JTX No. 3 is basically the same as that for JTX No. 1 and No. 2, except for the length of finned tube heat exchanger, and the expansion capillary tube sizes. JTX No. 3 is required to produce a higher gross refrigeration (70-100 milliwatts) at a higher inlet temperature (17-18 K) than either of the previous two. Therefore its finned tube section is longer and its capillary tubes are less restrictive.

The optical cavity dewar and helium tank are connected by a rigid vacuum-jacketed line interfacing with the existing fill quick disconnect and supply tube of the LM tank. A stainless steel-to-titanium coextruded transition tube is required at this interface in both the supply line and the vacuum jacket. A detail of this interface is shown in Drawing L197168*. Not shown is the installation of a temperature sensor which will be inserted into the 0.375 O.D. tank fill supply tube; with its leads passing through the optical cavity supply tube and out with the optical cavity instrumentation leads.

The helium tank and optical cavity dewar are supported by a framework of square tubing of sufficient sectional area to withstand the 9 g crash load from any direction. This mounting frame is not weight-optimized. Drawing L197168* shows the framework size for which a preliminary stress analysis was made in sufficient detail to check only the critical members. Low-cost 1010 carbon steel was selected for the uniform cross section frame, although in many areas lighter cross section area, or lighter-weight material, could be used. A detailed stress analysis and design iteration would be required to design a lighter weight frame.

The temperature controllers, control valves, warm-up coils, and other components are all commercially available equipment, and are described in the components section, or parts list, of this report.

*Included in Appendix A.

SECTION 3
SYSTEM OPERATION

SECTION 3

SYSTEM OPERATION

GENERAL

A flow schematic of the Astronomical Detector Cooling System is presented in Figure 3-1, showing how the LM helium tank would operate with the JTX-cooled optical cavity. Flow from the tank is split into two paths in the optical cavity dewar: (1) the JTX flow, which will be limited by its expansion capillary, to produce refrigeration at 2 K to 6 K, and (2) the VCS flow, which is the bulk of the tank flow, typically from 10 to 20 times greater than the JTX flow.

The VCS flow is used to pressurize the helium tank through the warm-up heat exchanger, pressure control valve, and tank internal heat exchanger. The other warm-up coil is used to warm the cold helium from the internal heat exchanger back up to room temperature for the flow control valve and flowmeter. It is best for all of these valves to operate at room temperature (prevents icing and simplifies their design). The pressure control valve, a 3-way by-pass type valve, is set at the minimum operating pressure desired for the tank, at which point the flow is diverted through the tank internal heat exchanger. This path will remain open during the entire pressure build-up period following tank filling. When buildup is achieved, the flow will by-pass the tank, passing directly to the flow control valve, which is set manually to achieve the desired flow rate as indicated by the flowmeter. An absolute flowmeter is not necessarily required here, if the flow control valve can be calibrated prior to system operation. The flow control valve also throttles the system pressure down to ambient pressure, or vents overboard.

The vacuum regulator valve controls the pressure at the JTX discharge, which in turn regulates the temperature at the exit of the J-T expansion capillary (unless the load temperature controller is active).

The tank is provided with a relief valve and emergency burst disc as safety devices. The relief valve will normally be used for high-pressure venting; the vent quick disconnect will be used for low-pressure venting.

A probable typical mission profile has been examined to determine the operating capabilities of this system. This is only one of a number of ways to operate the LM tank with the JTX cooling concept, thus is intended to be illustrative rather than definitive. The results of this preliminary study, without any system parametric variations (that is, selecting a specific fill quantity, tank flow rate, and operating pressure), are presented in Table 3-1, with tank quantity and temperature plotted in Figure 3-2. Each phase of operation is further discussed in the paragraphs below.

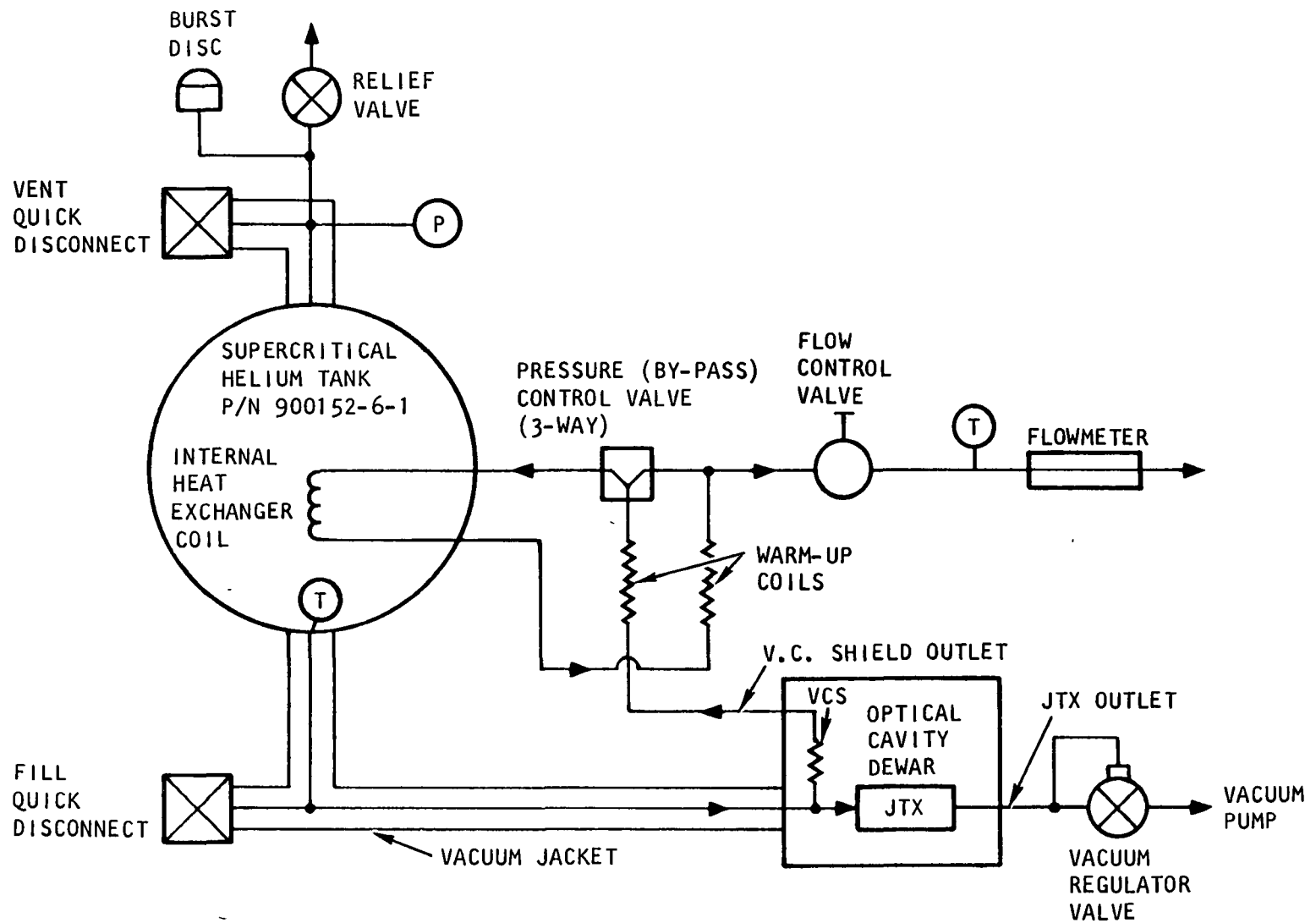


Figure 3-1. ADCS Flow Schematic (LM Helium Tank)

S-10424

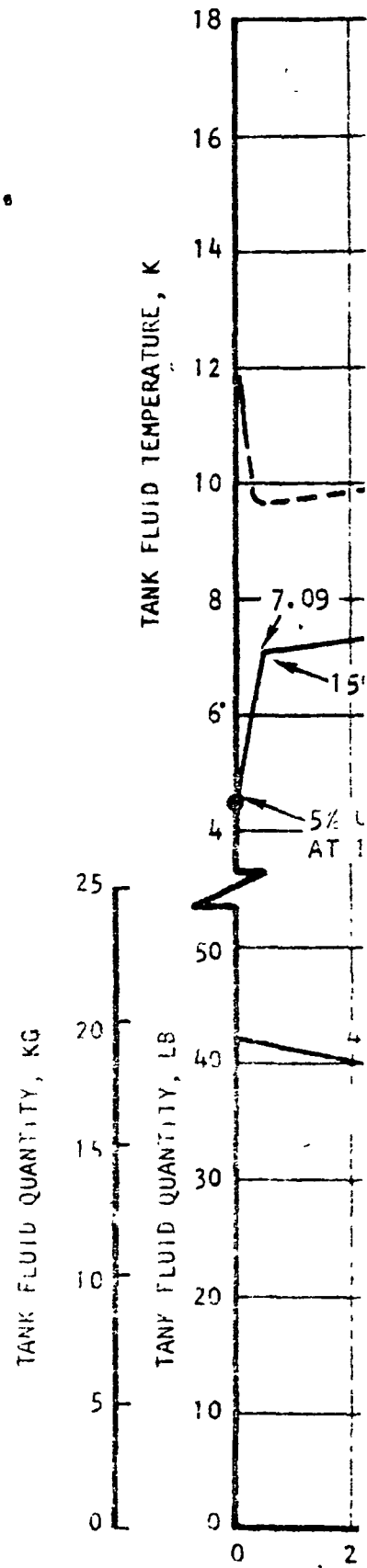
TABLE 3-1
KEY POINTS IN PROBABLE TYPICAL MISSION PROFILE (LM HE TANK)

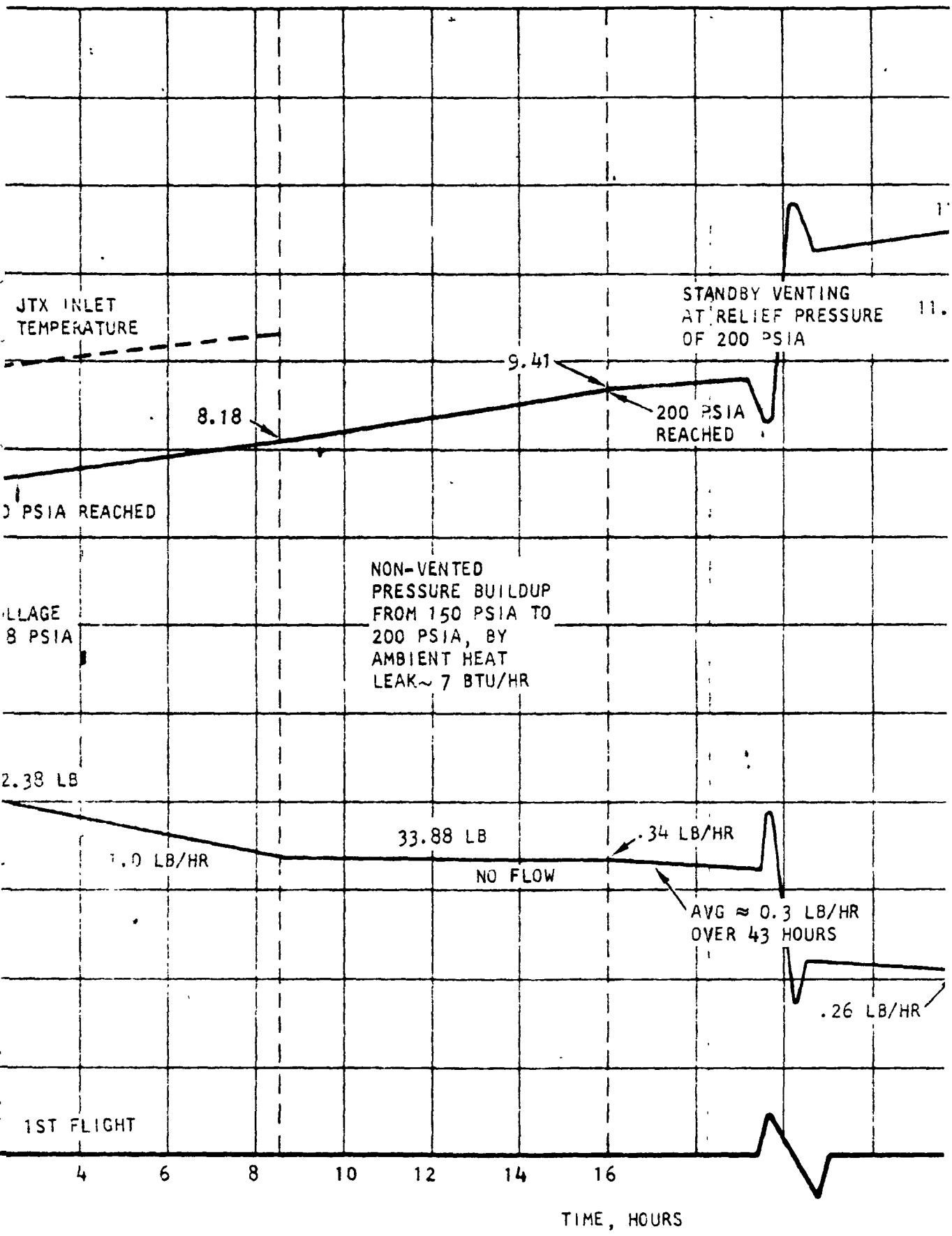
Time (hr)	Description of Event	Tank Fluid Quantity (kg)	Tank Fluid Temperature (K)	JTX Inlet Temperature (K)	JTX Gross Refrigeration (mW)	JTX Flow Rate (kg/hr)
0	Fill tank to 5% ullage at 1.225 atm.	19.22	4.45	--	--	--
0.5	JTX cooldown and tank build-up to 10.2 atm (150 psia) complete, using 0.454 kg/hr (1.0 lb/hr) from tank.	18.99	7.09	9.65	174	0.0454
8.5	End of 1st flight.	15.36	8.18	10.70	155	0.0449
16	No-flow pressure buildup to 13.6 atm (200 psia) completed. Start relief valve venting.	15.36	9.41	--	--	--
59	End of relief valve vent, average flow of 0.136 kg/hr due to 2.05 W tank heat leak.	9.53	13.00*	--	--	--
59+	Tank blowdown to 10.2 atm.	8.36	11.63	--	--	--
59.5	JTX cooldown complete. Start 2nd flight, using 0.454 kg/hr from tank (blowdown loss 1.17 kg)	8.14	11.85	14.4	101	0.0426
67	End of 2nd flight.	4.73	17.96	21.0**	35-40**	0.037-0.038

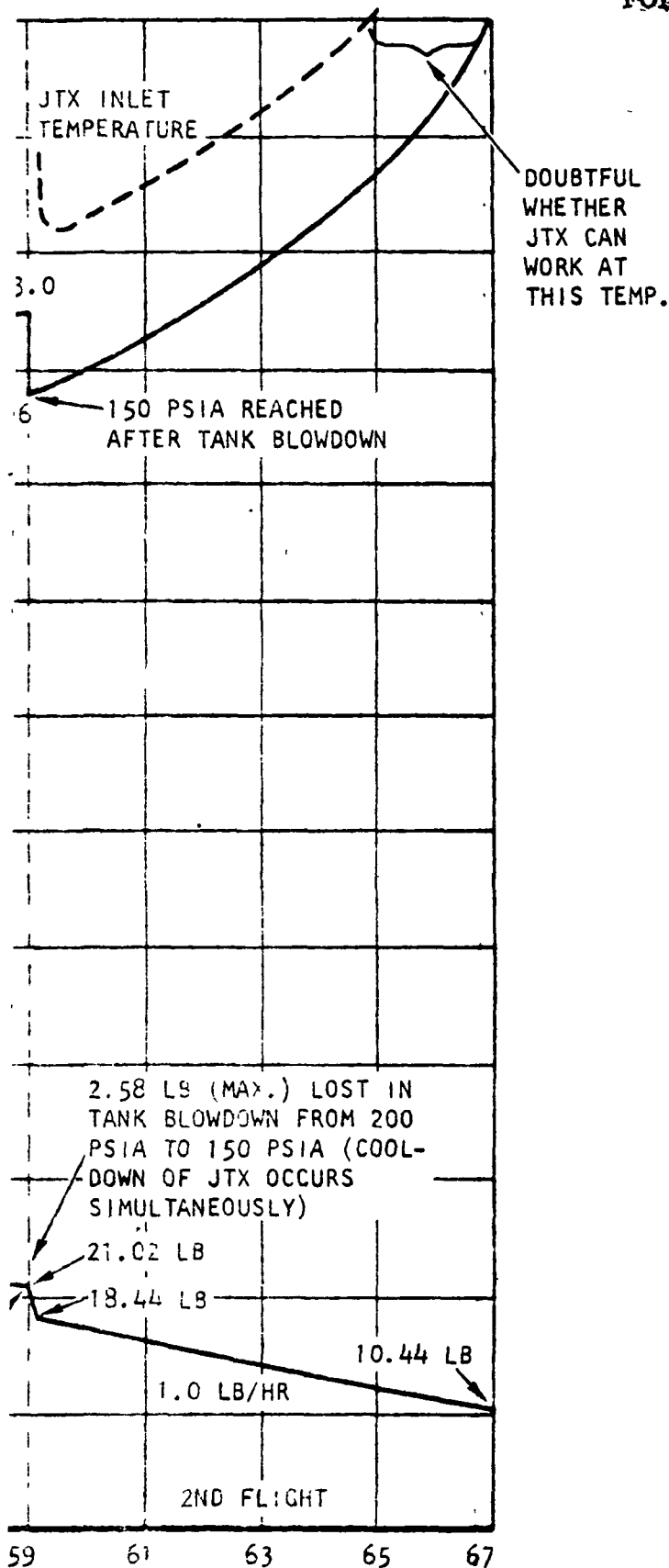
* Tank temperature at end of vent selected, 59 hr then calculated from vent rate and fluid quantity.

** JTX may not work at this high inlet temperature, reaching limit of 100% HX effectiveness. Maximum inlet temperature studied was 18 K.

FOEDGET FRAME 1







S-10394

Figure 3-2. LM Helium Tank Quantity and Temperature Profiles for Typical Mission

FILL PROCESS

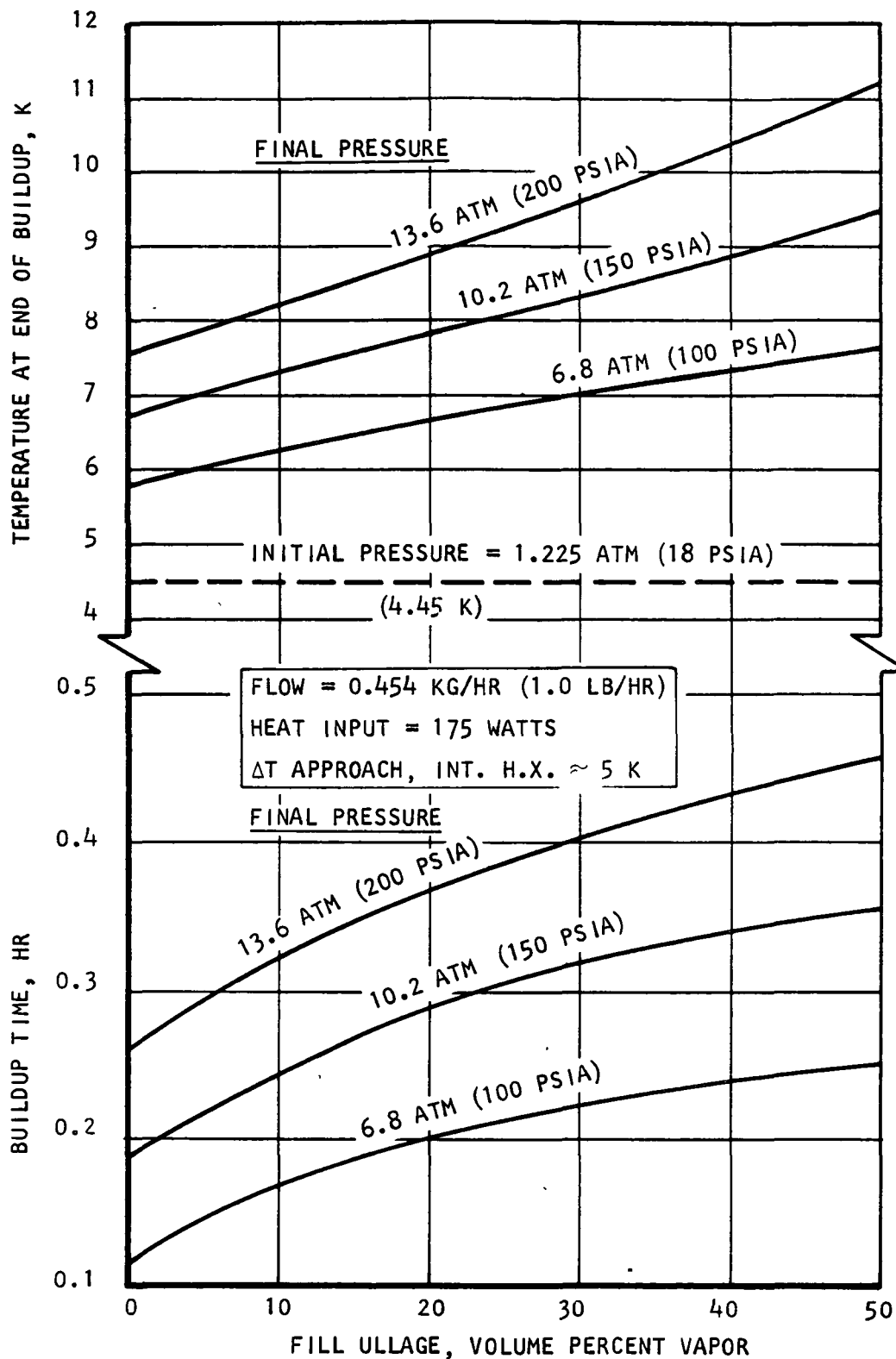
The LM helium tank can be filled to densities exceeding that of liquid at its normal boiling point by a supercharging technique, which requires special equipment to introduce cold gas up to moderately high pressures. For example, the helium tank for the Apollo 15 mission was filled with 24.4 kg (53.8 lb) of helium at 17.0 atm, which corresponds to a final helium temperature of about 6 K. This fill density is 17 percent higher than normal liquid density. In the present application, however, the fill equipment should be simple, thus fill quantities are limited to 95 to 99 percent liquid at some pressure slightly above atmospheric.

For the present study 1.225 atm (18.0 psia) was assumed for the fill pressure. The saturation temperature is 4.45 K. The primary fill parameter of interest, once the fill pressure is selected, is the ullage (vapor) volume fraction. As ullage volume increases so does the final tank temperature at the end of pressure buildup. Also, the time required to buildup pressure (for a given heat input) increases with increasing fill ullage volume. These effects on pressure buildup are presented later. For the maximum duration of JTX operation it is desirable to minimize the fill ullage. Since there is no way to measure the ullage volume in the LM tank, it is recommended that the tank fill process be continued until liquid appears at the vent disconnect. If the fill rate is high enough for rapid cooldown of the pressure vessel, this type of fill should allow a top-off resulting in from 1 to 5 percent ullage. For the typical mission examined here, 5 percent ullage was assumed. Once the tank pressure rises above the critical pressure, 2.25 atm, then the fluid quantity can be gauged from the pressure and temperature measurements.

TANK PRESSURE BUILDUP

The time required for tank pressure buildup to various pressures at different fill levels (ullage volume fraction) was estimated, and is shown in Figure 3-3. These results assume that a flow rate of 0.454 kg/hr (1.0 lb/hr) from the tank is established through the buildup heat exchanger coil, which is designed to heat the helium to 278 K (500 R) before entering the tank internal heat exchanger. Assuming that the internal heat exchanger exit temperature is about 5 K above the tank temperature, a net heat input of 175 watts results. Neglecting the ambient heat leak of about 2 watts, the curves show that for a 5 percent fill ullage, the pressure buildup to 10.2 atm (150 psia) takes about 0.22 hr (13 min), or about 0.10 kg (0.22 lb) of helium. Also shown in Figure 3-3 is the final tank temperature at the end of pressure buildup, as a function of fill ullage and final pressure. These curves show that the fill ullage volume effect is not very large at low values (less than 20 percent), which is fortunate since it is an unmeasurable parameter.

A preliminary design of the pressure control warm-up heat exchanger, using commercially-available finned tubing (for example, Voss "Miniature Tubing", a brazed finned tube, copper fins on stainless tubing), showed that a length of 1.8 m (6.0 ft), including a 30 percent margin, of 0.4762 cm (3/16 in.) tubing with overall diameter of 0.9525 cm (3/8 in.) and 15.7 fins/cm (40 fins/inch) would provide the 278 K outlet temperature with 0.454 kg/hr (1.0 lb/hr) of



S-10401

Figure 3-3. LM Helium Tank Estimated Pressure Buildup Characteristics

helium flow entering at 14 K. If the finned tubing were not used, it is estimated that the length of 0.9525 cm O.D. bare tubing would be 5.3 m (17.4 ft), without any design margin.

OPTICAL CAVITY COOLDOWN

A study of the preliminary-designed optical cavity dewar (presented under the Components Studies, Section 4) revealed that the VCS and the components within it (cold plate, JTX, etc.) could be cooled down from 300 K to their operating temperature (about 17 K) with 8.3 K inlet helium flowing at 0.907 kg/hr (2.0 lb/hr) in about 15 min. Although these assumed conditions are somewhat different from the operating point for the example mission, the cooldown time could be estimated for half that flow to be well within the 2-hour requirement. For purposes of the present discussion it could be estimated at closer to 1/2 hour. Since the pressure buildup time is less than this, the cooldown process would be occurring simultaneously with pressure buildup, and normal operation could begin well within one hour of the completion of filling.

If the mission profile of Figure 3-2 is used, the system flow control valve is closed (to minimize fluid loss), during standby venting of the tank. Thus the optical cavity will warm up (slowly) and cooldown would be repeated at the start of the second flight. However, very rapid cooldown would occur when the blowdown process is initiated through the flow control valve, since all the flow will go through the VCS, and the flow control valve would be wide open.

NORMAL OPERATION

When the helium tank normal operating pressure is reached and the JTX/optical cavity cooldown is complete, normal operation proceeds with the system flow, set by the flow control valve, being partially bypassed into the tank heat exchanger to maintain constant pressure. The pressure control valve will be open to the tank heater only momentarily, since the heat input requirement drops well below that for simply maintaining the control valves near room temperature. That is, the warmup coils are oversized for the case of normal pressure control. For example, when the tank fluid is between 7 K and 8 K at 10.2 atm (150 psia), and 0.454 kg/hr (1.0 lb/hr) is being withdrawn from the tank (at this point the system flow control valve would be set at about 0.408 kg/hr, since the balance from the tank would be passing through the JTX), the tank heat input requirement is only 4.9 W to maintain constant pressure, and about 2.1 W of this comes from ambient heat leak into the tank. The net heat input then requires a flow of only about 0.002 kg/hr into the tank heater.

The solid line in Figure 3-2 shows that the tank temperature profile is a strong function of fluid quantity in the tank. Note for the second flight how much faster the temperature rises than for the first flight. The dashed line represents the JTX inlet temperature, which although it follows the tank temperature profile, it is 2.5-3 K higher. This warmup is caused by the ambient heat into the connection between the tank and the optical cavity. A characterization of this heat leak as a function of flow rate and tank temperature are presented in the component studies section. It was estimated that about 43 percent of the transfer heat leak is due to the fill quick disconnect (which was not designed for low heat leak in the passive state).

One method to extend hold time between flights (without refilling) is noted in Table 3-1 and on Figure 3-2. This involves allowing pressure buildup to 13.6 atm (200 psia), by closing the flow control valve. This gives about 7.5 hr of no-flow hold time, where the only heat input to the tank is ambient heat leak. With the relief valve set at 13.6 atm, venting begins at a rate of about 0.154 kg/hr (0.34 lb/hr) and gradually tapers off to about 0.118 kg/hr (0.26 lb/hr) over a 43 hr period. In the example shown, the 43 hr was obtained by assuming a tank temperature of 13.0 K at the end of venting, then backing out the time period by iterating on the average flow rate, assuming a constant tank heat leak of 2.05 W. Perhaps a more meaningful calculation would be to select a time period and calculate the final temperature. In this case, however, it was desired to find the maximum hold time available between reasonable temperature levels over which the JTX system may work.

Prior to the second flight, the tank is subjected to an isentropic blowdown by fully opening the flow control valve (it should be sized for about 5 times the normal flow rate). Assuming an isentropic expansion is conservative since it results in the largest loss of fluid. During this blowdown back to 10.2 atm (at which point the flow control valve is reset to about 0.408 kg/hr) a high flow rate will be established through the optical cavity VCS serving to accelerate its cooldown for the second flight. The blowdown also cools the tank fluid slightly, allowing the JTX to operate for a longer time before its inlet temperature reaches the upper limit, above which liquid helium no longer appears at the cryostat cold tip. The exact limit of successful JTX operation at 2 K is not easily determined, therefore, it is noted that the last 2 hrs in Figure 3-2 may not count. Table 3-1 shows that the JTX gross refrigeration would probably be too low, and the detector would start warming up. At 65 hrs, it is estimated that about 62 mW of refrigeration would be available, enough to provide possibly 20 mW of detector cooling at 2 K. The characterization of the JTX performance and optical cavity heat leak are presented in the component studies section.

The minimum fill quantity required to just complete a single 8-hr mission was estimated to be 9.43 kg (20.8 lb), which represents an initial ullage volume of about 64 percent at 1.225 atm (18.0 psia). This was obtained by assuming the maximum JTX inlet temperature to be 18 K (yielding 62 mW of gross refrigeration at 2 K) at a tank pressure of 10.2 atm (150 psia). At this point the tank residual condition would be about 15.2 K, or 5.80 kg. Adding 3.63 kg (8.0 lb) to this quantity for the 8 hr flow period then gives the estimated fill quantity.

The mission profile presented in Table 3-1 and Figure 3-2 and discussed above is only one of a number of ways to operate the system in the C-141 Airborne Infrared Observatory. The emphasis of this study was on components, rather than broad-scale parametric study of system operation. Optimum system operation requires determining primarily the best operating pressure and flow rate, with fill quantity having a second order dependence, since it is not a measurable parameter. However, a cursory examination of two operating variations was made, addressing the following questions: (1) What is the effect of eliminating the blowdown and loss of fluid at 59 hrs, and resetting the pressure control valve to continue normal operation at 13.6 atm (200 psia); and

(2) What if venting at 10.2 atm (150 psia) were allowed for the 50.5 hrs between flights thus eliminating the pressure buildup to 13.6 atm and subsequent blowdown?

The first question asks how much warmer (if at all) the residual tank temperature would be by saving the 1.17 kg of helium exhausted during blowdown, and starting the second flight at 13.0 K instead of 11.6 K (tank fluid temperature). The answer is that the residual temperature will be 19.0 K rather than 18.0 K at 67 hrs, therefore it is better to blow down the tank at 59 hrs. This also avoids having to reset the pressure control valve.

The second question is, at first glance, a very promising alternative, simplifying system operation during the hold period. The calculation performed here assumes that the pressure control valve and relief valve are both set at 10.2 atm (in reality the relief valve must be set somewhat higher, maybe 0.5 to 1.0 atm higher). The results show that the tank quantity and temperature are 7.12 kg and 13.0 K, respectively, after 50.5 hr of venting at 10.2 atm. Then after 8 hr of flow at 0.454 kg/hr during the second flight, the residual tank temperature would be about 23.6 K rather than the 18.0 K with the pressure buildup and blowdown. This higher final tank temperature means that the JTX would cease producing refrigeration at 2 K much earlier in the second flight. Therefore, the mission exemplified in Figure 3-2 is better. The reason for this difference is twofold: first, the loss of fluid during the pressure buildup to relief pressure is eliminated (although most of the fluid saved is later lost in the blowdown), and secondly, the tank vent rate is slightly higher at the lower pressure (due to the helium thermodynamic property of specific heat input, which is lower at the lower pressure).

More details of the tank operating characteristics are given in the component studies section (Section 4).

SECTION 4
COMPONENT STUDIES

SECTION 4

COMPONENT STUDIES

OPTICAL CAVITY DEWAR

The primary requirement for the optical cavity dewar is to house the Joule-Thomson expander (JTX) and a variety of optical instruments and detectors (unspecified), with maximum versatility so that it can be used in a number of different scientific investigations. It is also to contain an optical cold plate approximately 12.7 cm (5.0 in.) in diameter. The cold plate must be completely removable through the top flange. Also, a 2.54 cm (1.0 in.) diameter infrared window is to be installed in the dewar cylindrical wall. The design therefore allows for a 2.54 cm diameter open path across nearly one diameter of the cavity to a mirror (G.F.E.) which reflects the beam to the detector(s) on the JTX cold tip. It is assumed that the incoming light beam thermal energy input is no greater than that from an aluminum lens cap radiating from room temperature. For an emissivity of 0.09 and a 300 K radiating temperature, this heat load amounts to 21 milliwatts.

The optical cavity dewar design study was performed in four steps. First, a preliminary thermal analyzer computer model was established with several design variations, to get a general idea of the magnitude of heat leak probable both with and without a vapor-cooled radiation shield (VCS). Secondly, a cooldown model with two design variations was established to determine the best attachment method of VCS, JTX and cold plate. At this point the preliminary design concept was selected and a layout drawing was prepared to formalize the concept into a workable design, and initiate preliminary stress analysis of the VCS and support system. The fourth step was to set up a final thermal analyzer model based on the Layout Drawing L197157*, and check the new steady-state heat leak. In the meantime the JTX had been designed (between steps 3 and 4), and although the optical cavity grew in overall dimensions (when finally drawn), the JTX size had decreased from the assumption in the preliminary thermal analyzer model. The final steady-state results were not significantly different, therefore the cooldown model was not revised.

The preliminary thermal model and its design variations were similar in concept to that shown in L197157; a bolted support system, rather than the felt pads shown, was also studied. The common features are: a copper can with removable top serving as a vapor-cooled radiation shield; and a stainless steel line brazed to the can, making two passes around the cylindrical wall and one loop around the bottom. The inlet supply line splits into the VCS cooling line and another line feeding the JTX through a filter. The JTX discharge vacuum line is the largest in the cavity, and is thermally shorted to the VCS to minimize conduction to the JTX. In addition to the supply interface and the JTX vacuum interface, there is a vacuum port for evacuating the entire cavity, and an instrumentation feed-through. All instrumentation leads are also thermally shorted (through a protective sheath) to the VCS to minimize their conduction to the JTX.

*Included in Appendix A.

A summary of the design parameters used in the preliminary thermal model are given in Table 4-1. The results of VCS and cold plate temperatures and cavity heat leak are presented in Table 4-2, for a given helium flow rate through the VCS tube, and two values of helium inlet temperature to the VCS. At that time these temperatures were assumed to be the range obtainable from a supercritical helium tank at 13.6 atm (200 psia) and a very low heat leak transfer line. Figure 4-1 displays graphically the heat leak results of Table 4-2. These results show that the heat leak to the JTX cold tip (at 1.67 K) increases as the JTX is thermally shorted to the cold plate, and then again as the combination is shorted to the VCS. As seen from Table 4-2, the lowest temperature cold plate is obtained by shorting the JTX to the cold plate, only; maintaining some thermal isolation from the VCS. The results presented are encouraging, in that heat leaks below 100 mW can be absorbed by a reasonable-sized JTX, as will be discussed later. The primary reason for such low heat leaks is the cooling effect of the helium flowing through the VCS. The VCS intercepts the bulk of the heat entering the cavity from ambient, by radiation, support system conduction, and line and instrumentation leads conduction. A study of the effect of VCS flow rate on cavity heat leak was performed for the baseline model and the bolted VCS model. The results are plotted in Figures 4-2 and 4-3, and show the significant effect of vaporcooling as flow rate is decreased. The estimated heat leaks with no flow were 750 mW and 880 mW, for the baseline and bolted VCS, respectively. The bolted VCS model is probably somewhat conservative, since in reality the bolt conduction is so high that the outer cavity wall will definitely frost or ice. The frost will create an insulating layer resulting in a lower bolt temperature and therefore a lower heat rate. It was not intended to design the cavity with a bolted VCS, but only to examine the extremes of support system design on thermal performance. The most important result of this study was demonstrating the tremendous effect of vapor cooling a radiation shield, even with grossly different support systems. The added complexity of incorporating a VCS is far outweighed by the gain in thermal performance.

From the steady-state analysis above, the minimum heat leak design would have the JTX and cold plate thermally insulated from the VCS (Kel F spacer). However, for rapid cooldown, since the highest flow of helium is to the VCS, it is most desirable to provide a good thermal path between the JTX and VCS. This is demonstrated by two cooldown models analyzed. The first one, based on the bolted VCS baseline, has Kel F spacers between the cold plate and VCS. With 0.907 kg/hr of helium at 8.3 K entering the VCS, cooldown of the VCS from 300 K to 30 K was accomplished in 10 minutes. But in the same time period the JTX and cold plate had barely moved from 300 K. This is shown in Figure 4-4. Figure 4-5, on the other hand, shows the cooldown transient for the same helium conditions with JTX and cold plate shorted to the VCS. This model also includes the 100 gm copper equivalent of unspecified optical equipment on the cold plate. The cooldown time shown in Figure 4-5 is about 15 minutes, for the entire optical cavity. At this point it was decided to design the cavity with JTX and cold plate shorted to the VCS.

TABLE 4-1

OPTICAL CAVITY DEWAR
PRELIMINARY THERMAL MODEL
DESCRIPTION

Model Designation	Model Description
VCS1 (Baseline)	<p><u>VCS (OFHC copper)</u> Outside diameter = 15.24 cm (6.0 in.) Outside height = 6.30 cm (2.48 in.) Thickness = 1.65 mm (0.065 in.)</p> <p><u>Outer Vacuum Wall</u> Inside diameter = 17.78 cm (7.0 in.) Inside height = 8.20 cm (3.23 in.)</p> <p><u>Support Pads</u> (compressed micro quartz felt, use conductivity for AA1200 fiberglass) Total area = 91.21 cm² (14.14 in.²) Thickness = 1.27 cm (0.5 in.)</p> <p><u>VCS Cooling Line</u> (stainless steel) Outside diameter = 0.318 cm (0.125 in.) Wall thickness = 0.305 mm (0.012 in.) Attached length = 106.7 cm (42 in.) Perfect contact (brazed) around 60° of tube diameter</p> <p><u>JTX Vacuum Line</u> (stainless steel) Outside diameter = 0.953 cm (0.375 in.) Wall thickness = 0.254 mm (0.010 in.) Length on each side of VCS = 15.95 cm (6.28 in.)</p> <p><u>Instrument Leads</u> (ETP Copper) 8 each AWG 40, diameter = 0.0787 mm (0.0031 in.) 4 each AWG 30, diameter = 0.254 mm (0.010 in.) Length on each side of VCS = 15.24 cm (6.0 in.)</p> <p><u>Cold Plate Support</u> (Kel F brackets) Total area = 4.84 cm² (0.75 in.²) Height = 1.27 cm (0.50 in.)</p> <p><u>JTX Mounting Bracket</u> (stainless steel) Area = 0.161 cm² (0.025 in.²) Length = 1.27 cm (0.50 in.)</p> <p><u>JTX Sheath</u> (L605, use conductivity of stainless) Outside diameter = 1.27 cm (0.50 in.) Wall thickness = 0.254 mm (0.010 in.) Length of cold tip = 1.27 cm (0.50 in.)</p>
MOD1	JTX mounting bracket changed to OFHC copper, and moved next to cold tip
MOD2	In addition to MOD 1, copper washers (3) replace Kel F cold plate supports washer diameter = 1.27 cm (0.50 in.) washer thickness = 0.635 cm (0.25 in.)
BOLTS	Same as VCS1 (Baseline) except that compressed micro quartz felt pads are replaced by 3 stainless steel bolts, with Kel F spacer block Bolt diameter = 0.318 cm (0.125 in.) Bolt conduction length = 1.27 cm (0.50 in.) Kel F spacer diameter = 1.91 cm (0.75 in.)
BOLTS1	MOD 1 applied to BOLTS model
BOLTS2	MOD 2 applied to BOLTS model

TABLE 4-2

OPTICAL CAVITY DEWAR PRELIMINARY THERMAL MODEL RESULTS

Helium Pressure = 13.6 atm (200 psia)

Ambient Temperature = 300 K

Helium Flow to VCS = 0.907 kg/hr (2.0 lb/hr)

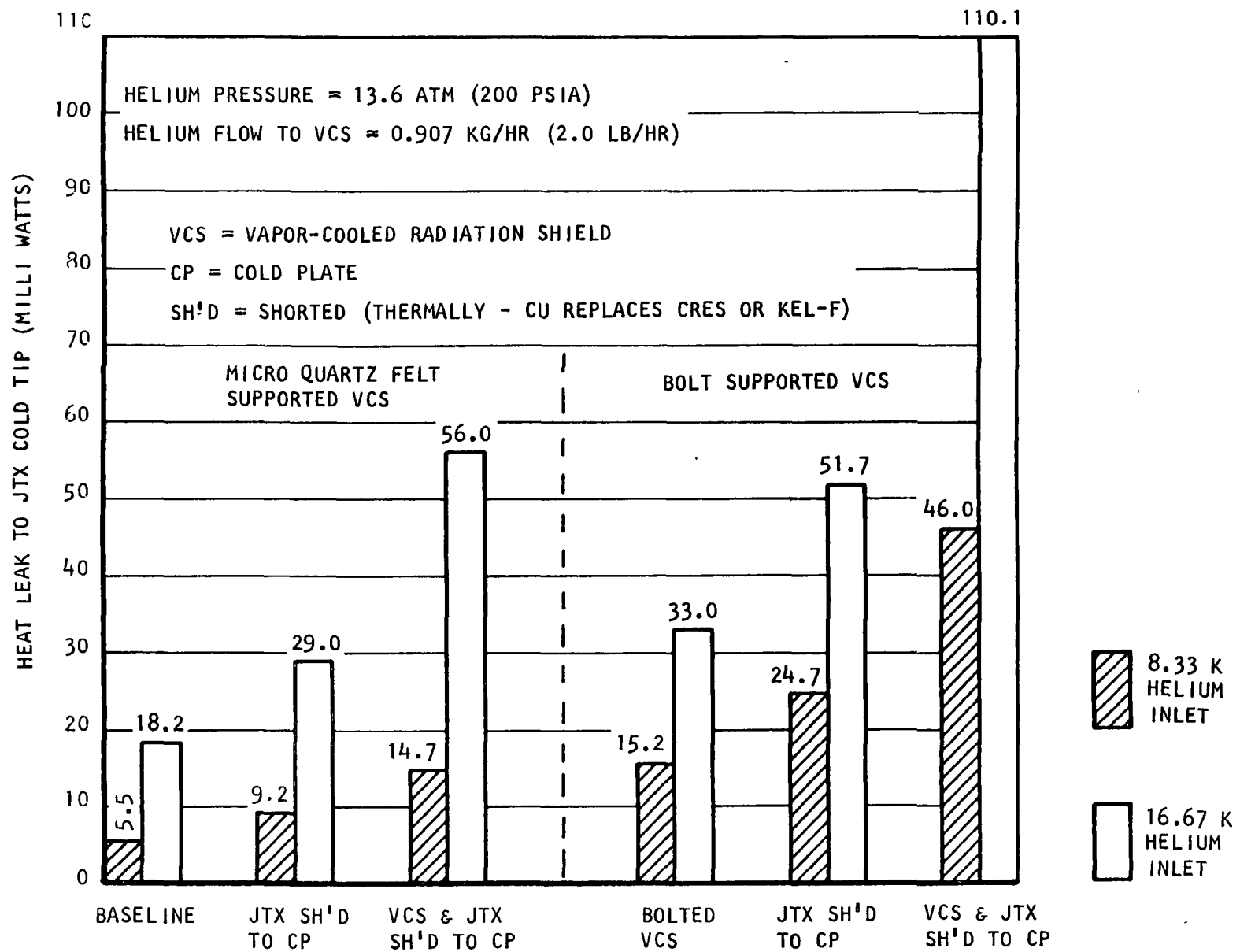
JTX Cold Tip Temperature = 1.67 K

Model Designation	Model Description	VCS Inlet = 8.33 K			VCS Inlet = 16.67 K		
		T _{VCS} (K)	T _{CP} (K)	Q (mW)	T _{VCS} (K)	T _{CP} (K)	Q (mW)
VCS1	Baseline (Micro Quartz Felt Supports)	10.6	10.0	5.5	18.5	17.0	18.2
MOD1	JTX Shorted to Cold Plate	10.6	8.1	9.2	18.4	12.7	29.0
MOD2	VCS & JTX Shorted to Cold Plate	10.6	10.6	14.7	18.4	18.4	56.0
BOLTS	Bolted VCS Supports	17.0	15.7	15.2	24.9	22.0	33.0
BOLTS1	Bolted VCS, JTX Shorted to Cold Plate	17.0	11.9	24.7	24.8	16.0	51.7
BOLTS2	Bolted VCS Shorted to JTX & Cold Plate	17.0	17.0	46.0	24.8	24.8	110.1

The design Layout Drawing L197157* shows the details of the optical cavity dewar, including the JTX, cold plate, VCS, and the compressed micro quartz felt pad support system. The stress analysis of this component focused on two areas: (1) support pad design and (2) VCS thickness. The natural frequency of the compressed pads is estimated to be 136 Hz, well above the 3 Hz cutoff of the telescope isolation system, thus none of the vibration modes in this system will be excited. The 4.8 atm (70 psi) preload on the side support pads is too high for the 1.65 mm (0.065 in.) thick OFHC copper VCS. Therefore a 4.78 mm (0.188 in.) thick gusset is designed into the inner cylindrical surface of the VCS behind each support pad. The stresses at the bottom plate of the VCS were also checked. For the 9-g vertical load (1.51 kg supported weight) the calculated margin of safety in the 1.65 mm thick copper was 0.88.

The final analytical study of the optical cavity dewar was to revise the thermal analyzer model to reflect the design as presented in Drawing L197157*, and determine the cavity heat leak and helium outlet temperature as a function of helium flow rate and inlet temperature. These curves were used later in the systems analysis, and in determining a portion of the cooling load required by the JTX. Figures 4-6 and 4-7 present the results of the final thermal model of the optical cavity dewar.

*Included in Appendix A.



S-10400

Figure 4-1. Optical Cavity Dewar Preliminary Thermal Model Heat Leak Study

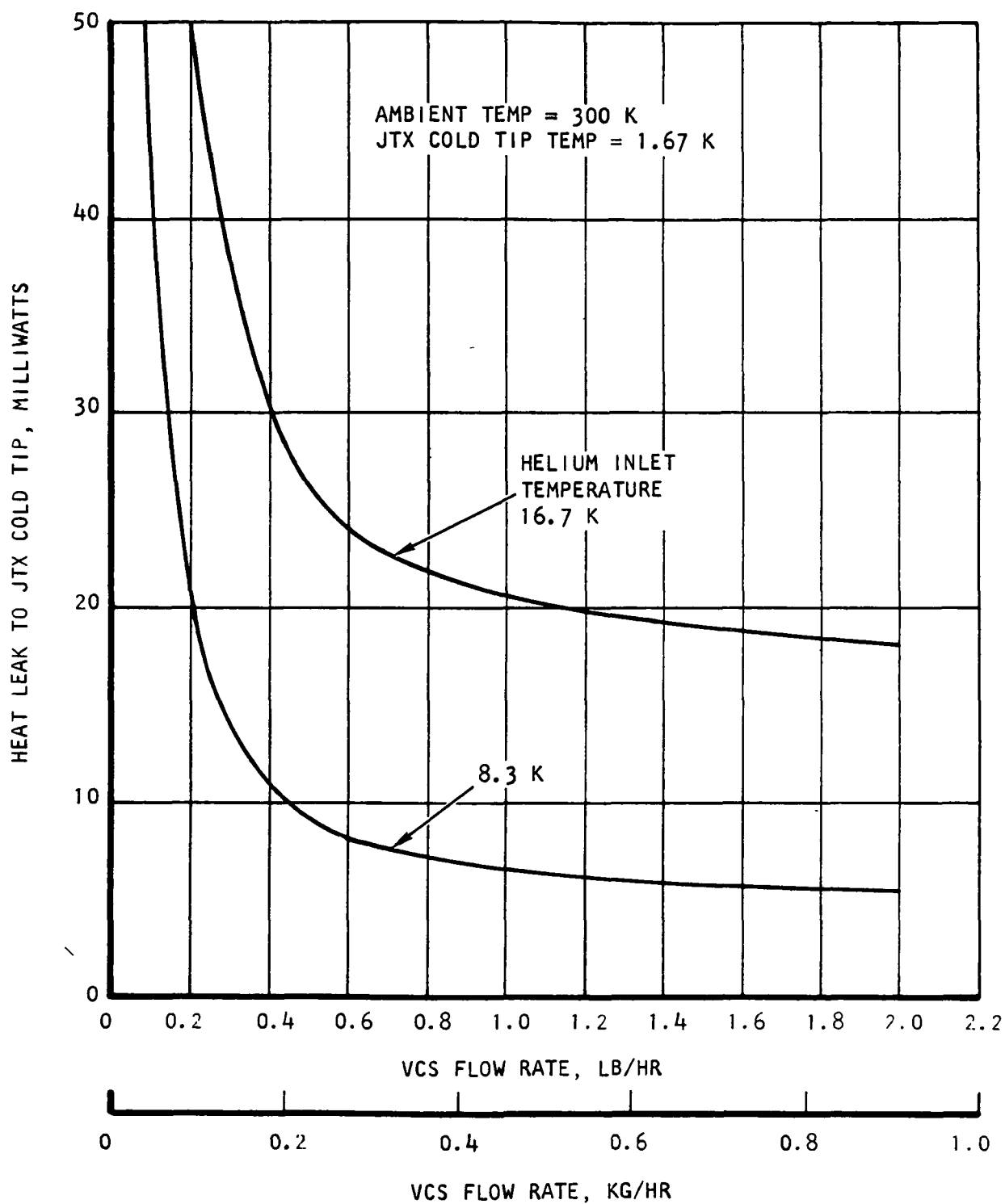


Figure 4-2. Optical Cavity Dewar Heat Leak as a Function of VCS Flow Rate - Baseline Model

S-10434

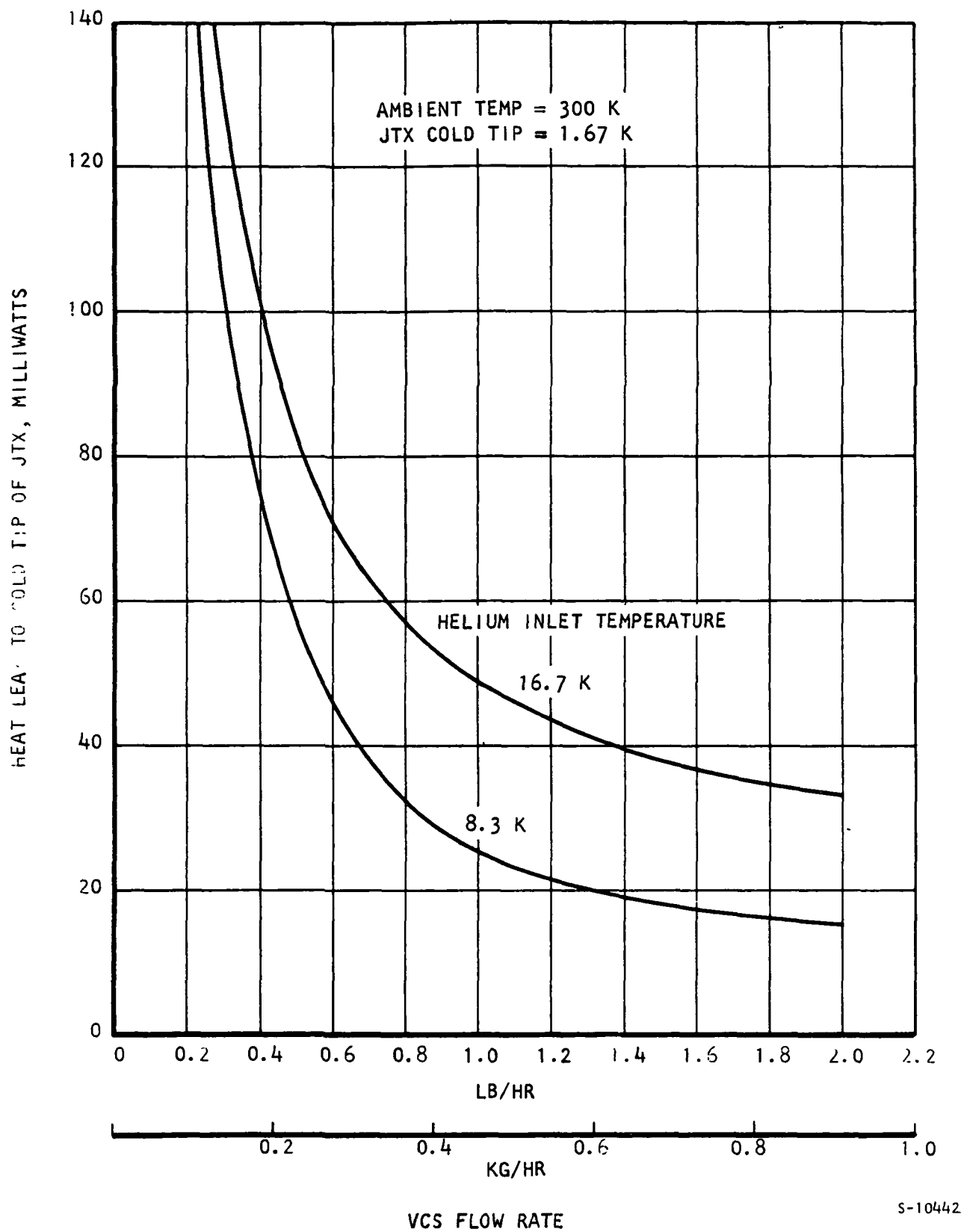


Figure 4-3. Optical Cavity Dewar Leak as a Function of VCS Flow Rate - Bolted VCS Model

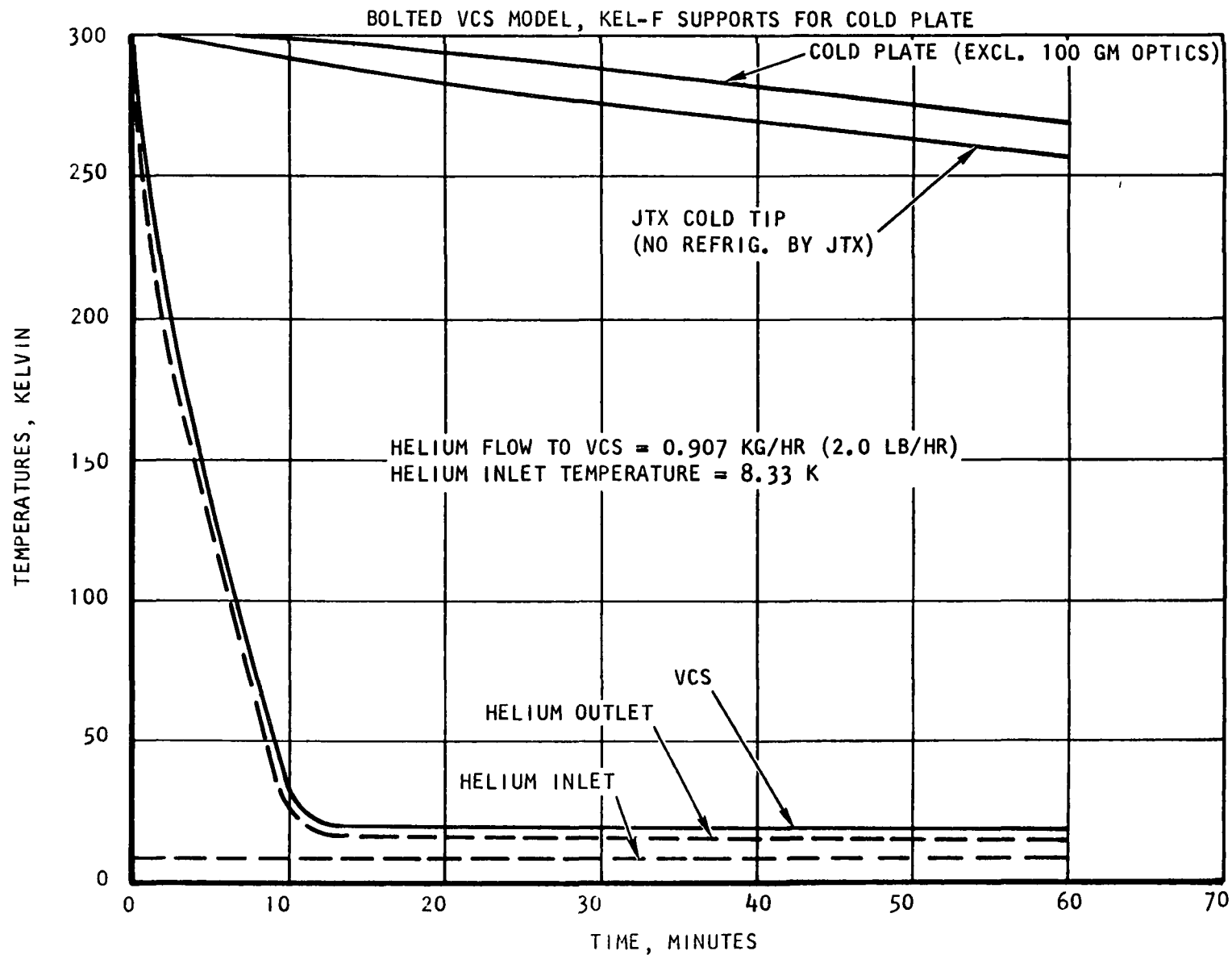


Figure 4-4. Optical Cavity Dewar Cooldown - Cold Plate Isolated from VCS

S-10437

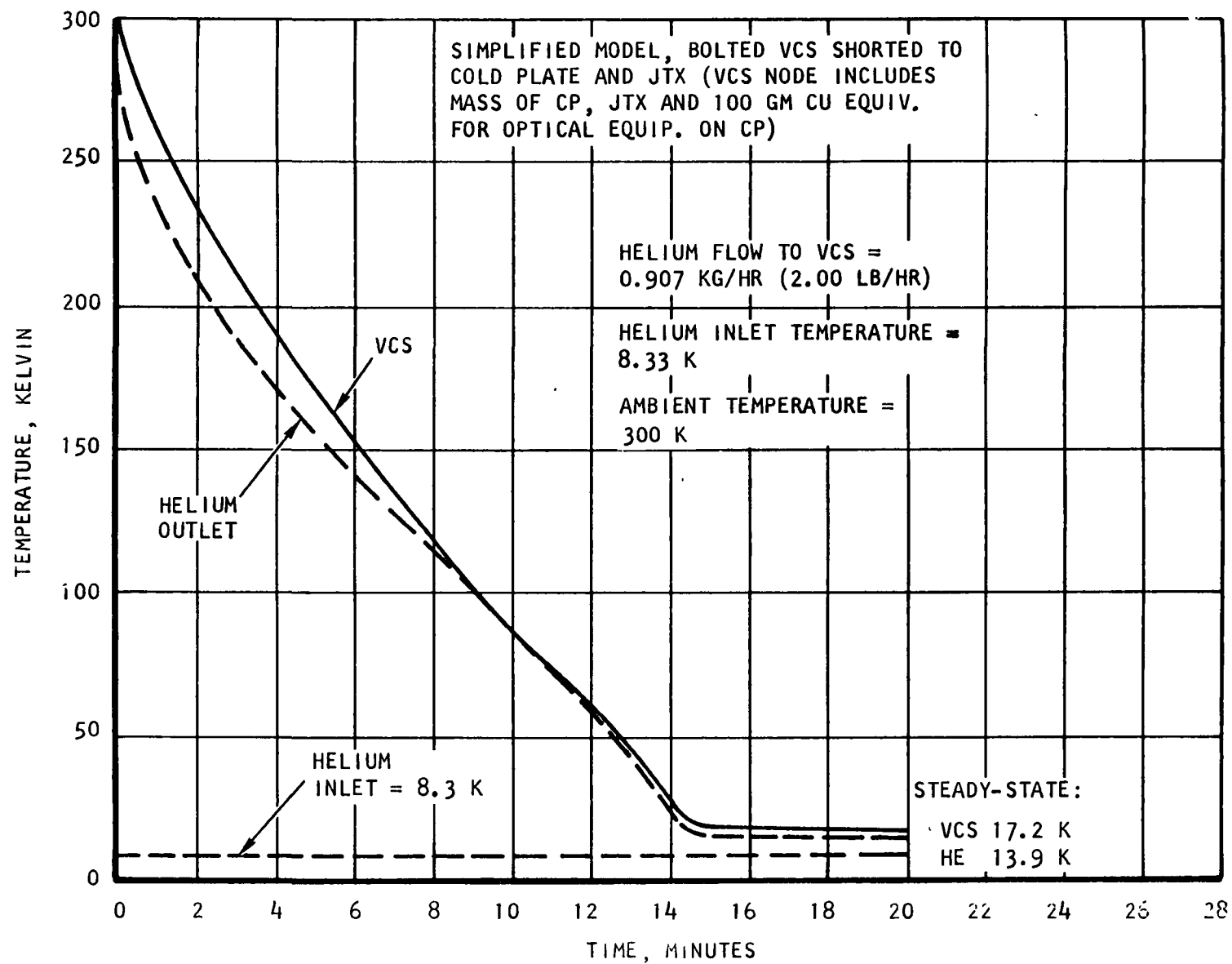
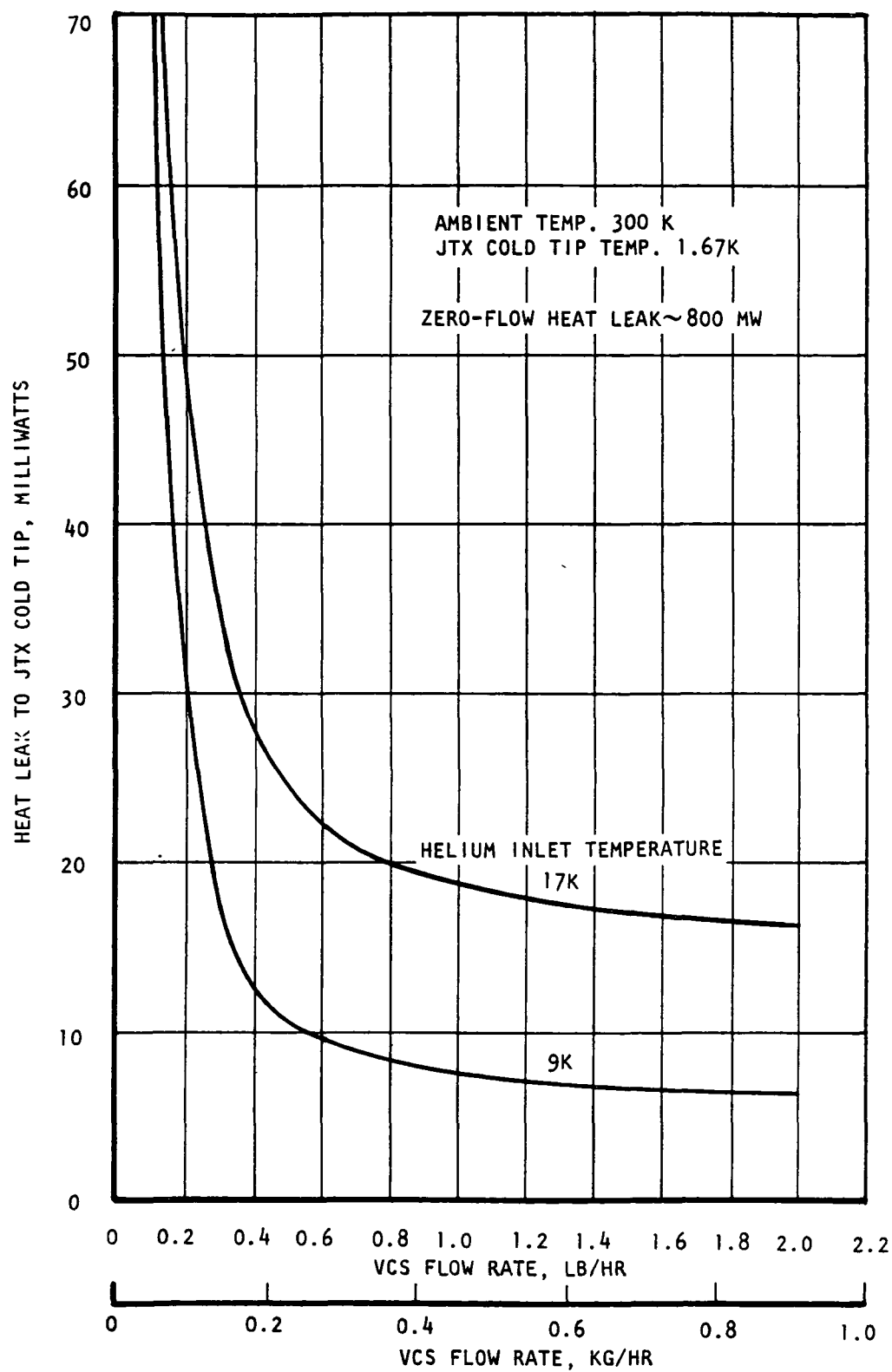


Figure 4-5. Opt. cal Cavity Dewar Cooldown - Cold Plate Shorted to VCS

S-10436



S-10399

Figure 4-6. Optical Cavity Dewar Heat Leak as a Function of VCS Flow Rate--Final Model

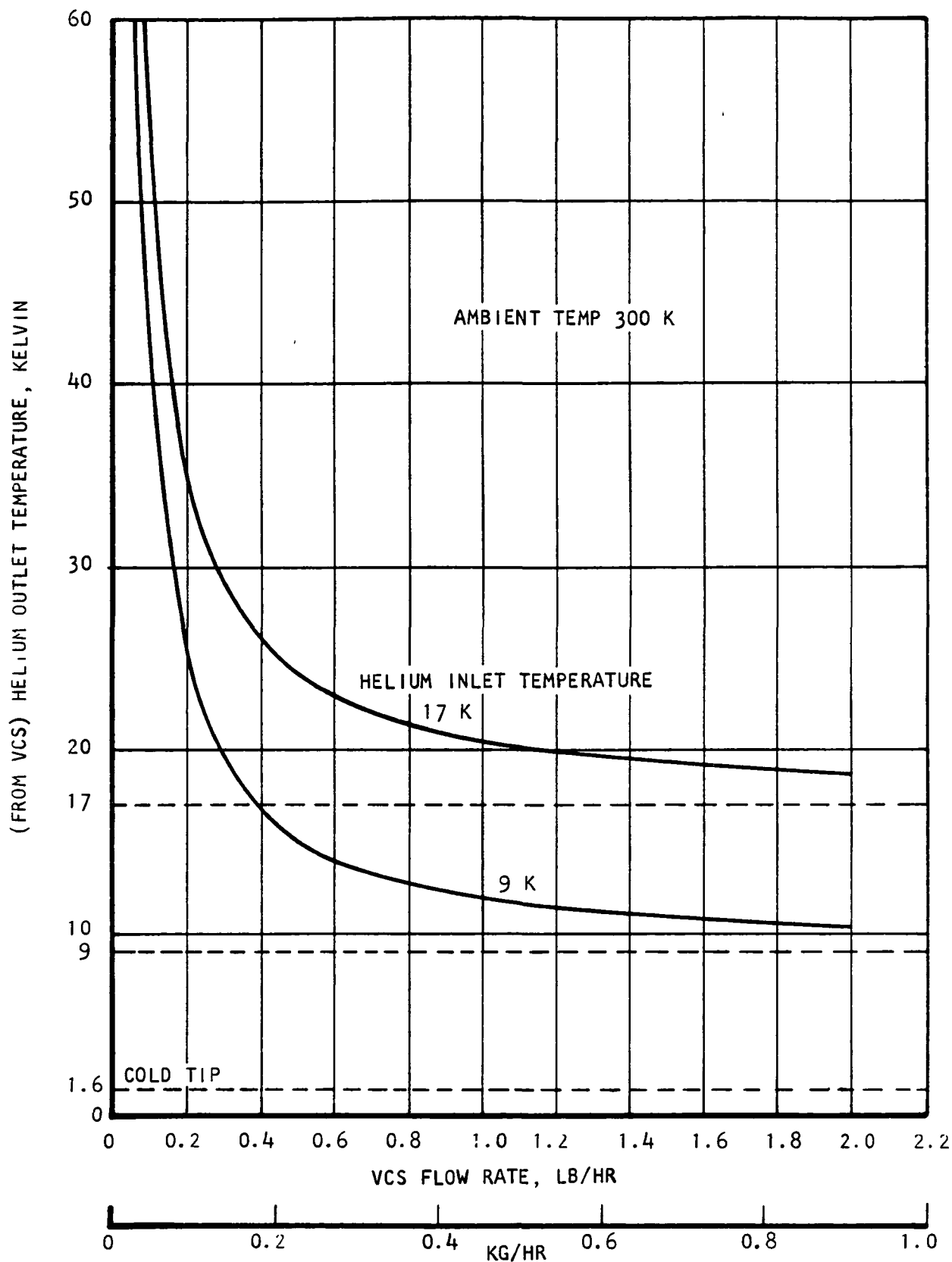


Figure 4-7. Optical Cavity Dewar Helium Outlet Temperature From VCS as a function of Flow Rate - Final Model

S-10433

JOULE-THOMSON EXPANDER (JTX)

The Joule-Thomson expander and heat exchanger, JTX No. 3 under the original contract, is identical in concept to JTX Nos. 1 and 2. Only the finned tube length and capillary tube sizes are changed to obtain the desired refrigeration.

These units are designed by a performance prediction computer program developed under the original contract, and are documented in another report.* For this study it was expected that the JTX size would increase significantly in order to handle the additional load due to optical cavity dewar heat leak. The first JTX was designed for testing in a 4.2 K liquid helium bath. It turns out that the same sheath, mandrel, and finned tube sizes can be made to produce the required refrigeration for the optical cavity detectors.

The design point for the JTX was first taken to be 100 mW at an inlet temperature of 17 K and pressure of 13.6 atm (200 psia), before the final optical cavity dewar design was established, and no system analysis had been performed. The high inlet temperature is chosen to represent the supply fluid state at the end of a mission--it yields the lowest refrigeration. At the start of a mission, the supply helium is colder and the JTX produces more refrigeration. The final design point, after selecting an operating pressure of 10.2 atm (150 psia) is 72 mW. This gross refrigeration allows for 30 mW of detector cooling (system requirement) and 42 mW of optical cavity heat leak (21 mW each from the VCS and the IR window).

The JTX is designed by selecting the design point inlet conditions above and a load temperature of 2.0 K (pressure of 23.8 torr at the inlet to the low-pressure side of the heat exchanger), and running a series of computer cases for variable heat exchanger tube length and capillary tube length. A capillary tube inside diameter of 0.1016 mm (0.004 in.) was selected because it is the most readily available. The next lowest standard size is half that, and would restrict the flow too much in this cryostat. After cross-plotting gross refrigeration versus tube lengths, a 61 cm (24 in.) heat exchanger length and a 46 cm (18 in.) small capillary tube length were found to give 100 mW at the 17 K, 13.6 atm inlet condition. A complete tabulation of the JTX cryostat design parameters is given in Table 4-3.

With the selected design parameters, the computer program is then re-run for a large number of inlet conditions. Since the program involves a double iterative calculation, some cases do not converge, hence results are "smoothed" and cross-plotted to arrive at a performance map. This map, presented in Figure 4-8, shows a dashed limiting line at the top which approximately defines a fluid properties lookup limitation. This is not serious, since the refrigeration available at those inlet conditions is much higher than the design value. The flow rate results over the same range of conditions are presented in Figure 4-9. This shows that the range of flows required by the JTX at the intermediate pressures are about 1/10 to 1/20 of the total flow delivered from the

* "Final Technical Report, Joule-Thomson Expander and Heat Exchanger,"
AiResearch Report No. 76-13285, November 30, 1976.

TABLE 4-3
JTX NO. 3 DESIGN PARAMETERS

Parameter	Centimeters	Inches
High pressure tube I.D.	0.03048	0.012
O.D.	0.05588	0.022
Fin O.D.	0.12446	0.049
Mandrel O.D.	0.5080	0.200
Coil diameter	0.6401	0.252
Sheath I.D.	0.7874	0.310
O.D.	0.8052	0.317
Fin thickness	0.01041	0.0041
Fin pitch	0.0254	0.010
Finned tube length	60.96	24.0
Coiled length	4.064	1.60
Overall Mandrel length (approx)	5.588	2.20
Small capillary tube I.D.	0.01016	0.004
O.D.	0.02032	0.008
length	45.72	18.0
Large capillary tube I.D.	0.0254	0.010
O.D.	0.0457	0.018
length	30.48	12.0

supercritical helium tank. This allows a high flow to be bypassed through the VCS to effect high cooling, thus minimizing heat leak to the JTX.

SUPERCRITICAL HELIUM TANK

The requirements for the helium tank are as follows:

- Sufficient capacity to operate the system for 8 hours
- Design for simplicity of loading with absolute minimum of external loading equipment
- Capable of being pressurized to 20 atm at 9.0 K, and be tested to 30 atm at 11.0 K
- Pressure and temperature monitoring capability
- Equipped with redundant relief valve and burst diaphragm
- Mounting brackets to be of sufficient strength to retain the tank under a 9-g impact from any direction

Three options were investigated to satisfy the above requirements:

- Lunar Module (LM) Helium Tank, Drawing number 900155

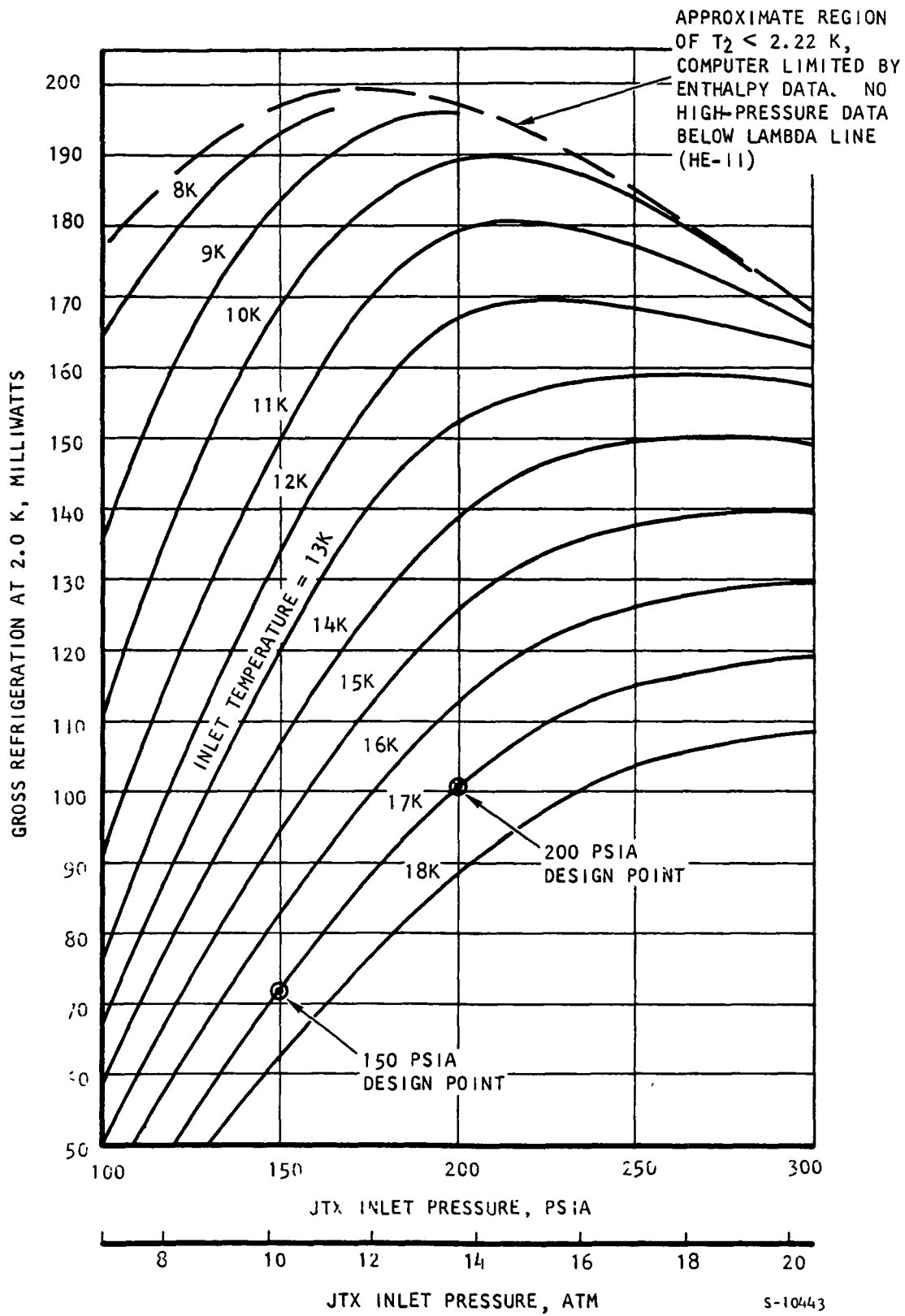
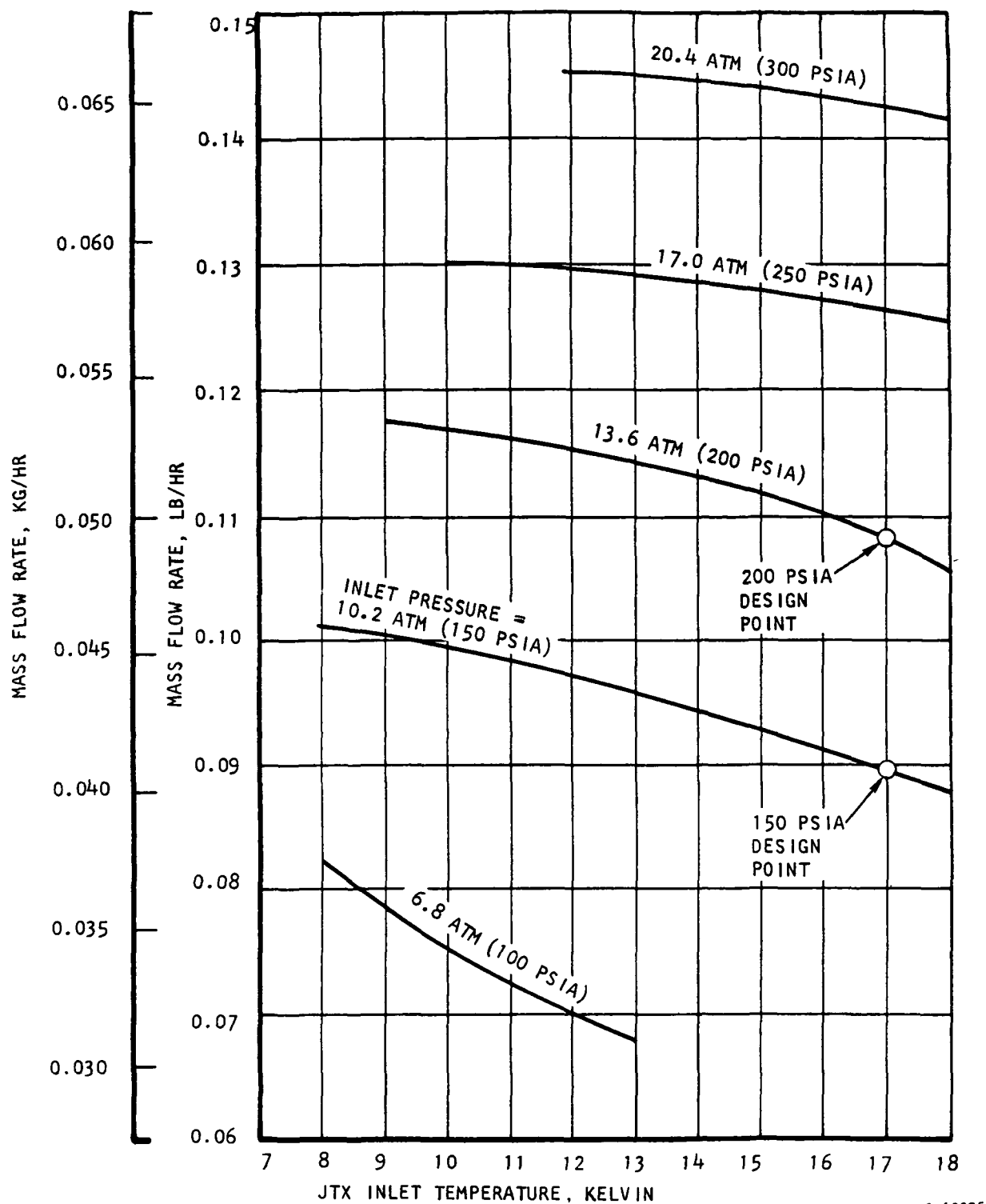


Figure 4-8. JTX No. 3 Performance Prediction Map for 2K Refrigeration



S-10395

Figure 4-9. JTX No. 3 Flow Rate Prediction for 2K Refrigeration

- MSFC H₂/He (MOL) Tank, Drawing number 851240
- Commercial Dewar

Most of the following discussion will be concerned with the first two options, the performance characteristics of each, as we have determined them through testing, and the pros and cons associated with using either one in this system. The commercial dewar information is limited to that obtained from the manufacturer and was not subjected to a detailed analysis at AIResearch.

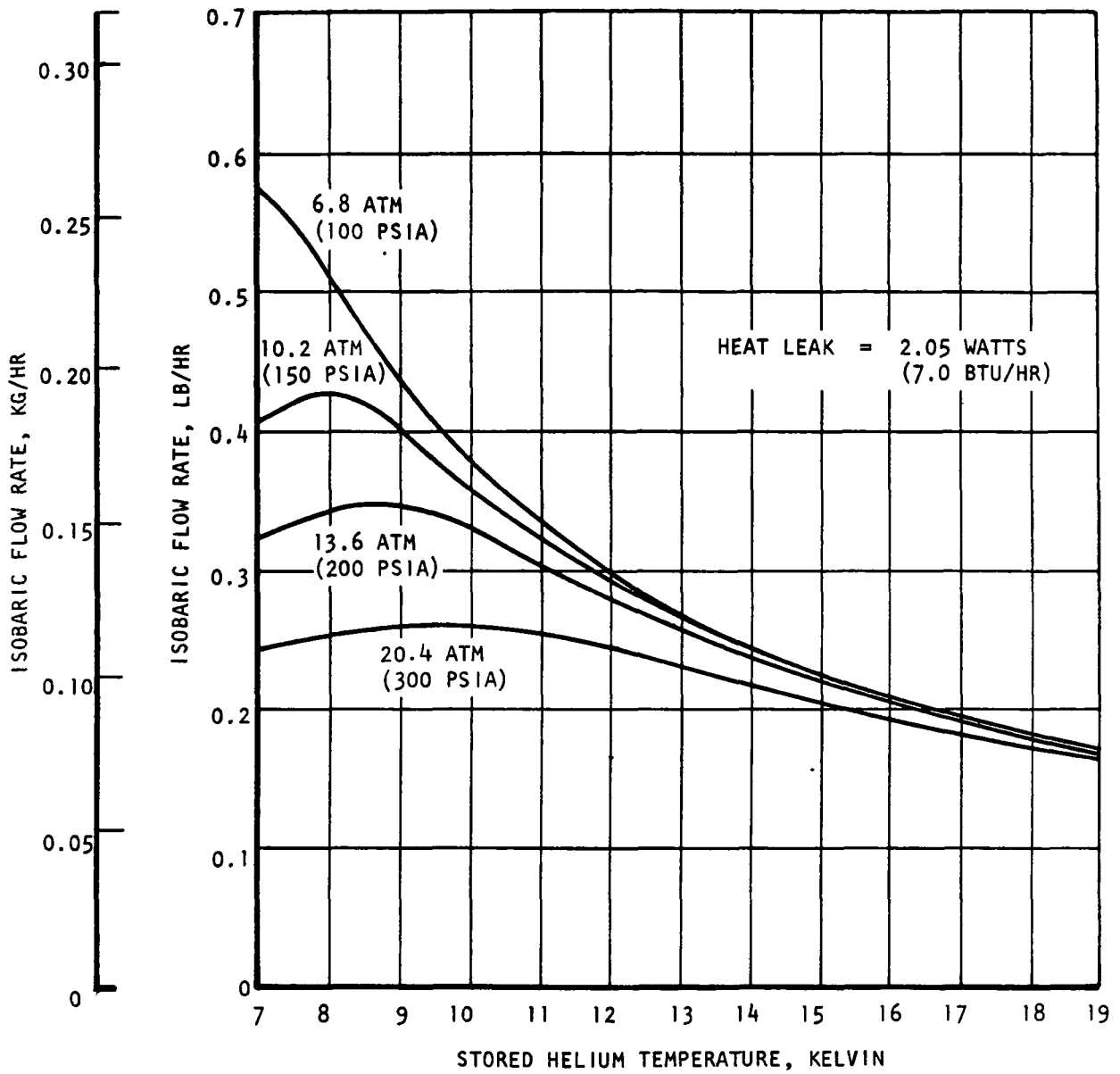
LM Helium Tank

This tank was designed to supply high-pressure helium to the propellant tanks of the Lunar Module descent engine. The helium was stored in the cryogenic state to minimize storage volume and weight, and as a consequence, was weight-optimized through extensive use (almost 100 percent) of titanium alloy 5 Al 2.5 Sn ELI. The outer shell O.D. is 83.8 cm (33.0 in.), the pressure vessel I.D. is 68.5 cm (27.0 in.). The volumetric storage capacity at 4.2 K is about 167 liters (5.89 cu ft), and the tank has been filled with up to 24.5 kg (54 lb). The maximum dry weight of the tank assembly, including external flight hardware is 52 kg (115 lb). The insulated annulus consists of aluminized-Mylar superinsulation and AA1200 heat-felted compressed fiberglass support pads. The tank available at Houston, P/N 900152-6-1, S/N 66-104, originally demonstrated an average heat leak over a 131-hr pressure buildup period of 2.05 watts (7.0 Btu/hr) at 311 K ambient temperature. The tank is equipped with a pressure control internal heat exchanger, consisting of 3.35 m (11.0 ft) of 1.27 cm (0.5 in) O.D. by 0.762 mm (0.030 in.) wall titanium tubing coiled in the bottom of the pressure vessel (this location minimizes thermal stratification). A small orifice shunt between the inlet and outlet heat exchanger tubes on the outer shell serves to prevent thermal acoustic oscillations.

The predicted vent rate of the subject tank operated at various pressures is presented as a function of stored helium temperature in Figure 4-10. These curves are based on the predicted heat leak of 2.05 watts, and the specific heat input of helium plotted in Figure 4-11. The specific heat input data are taken from NBS Technical Note 622, issued September 1972.

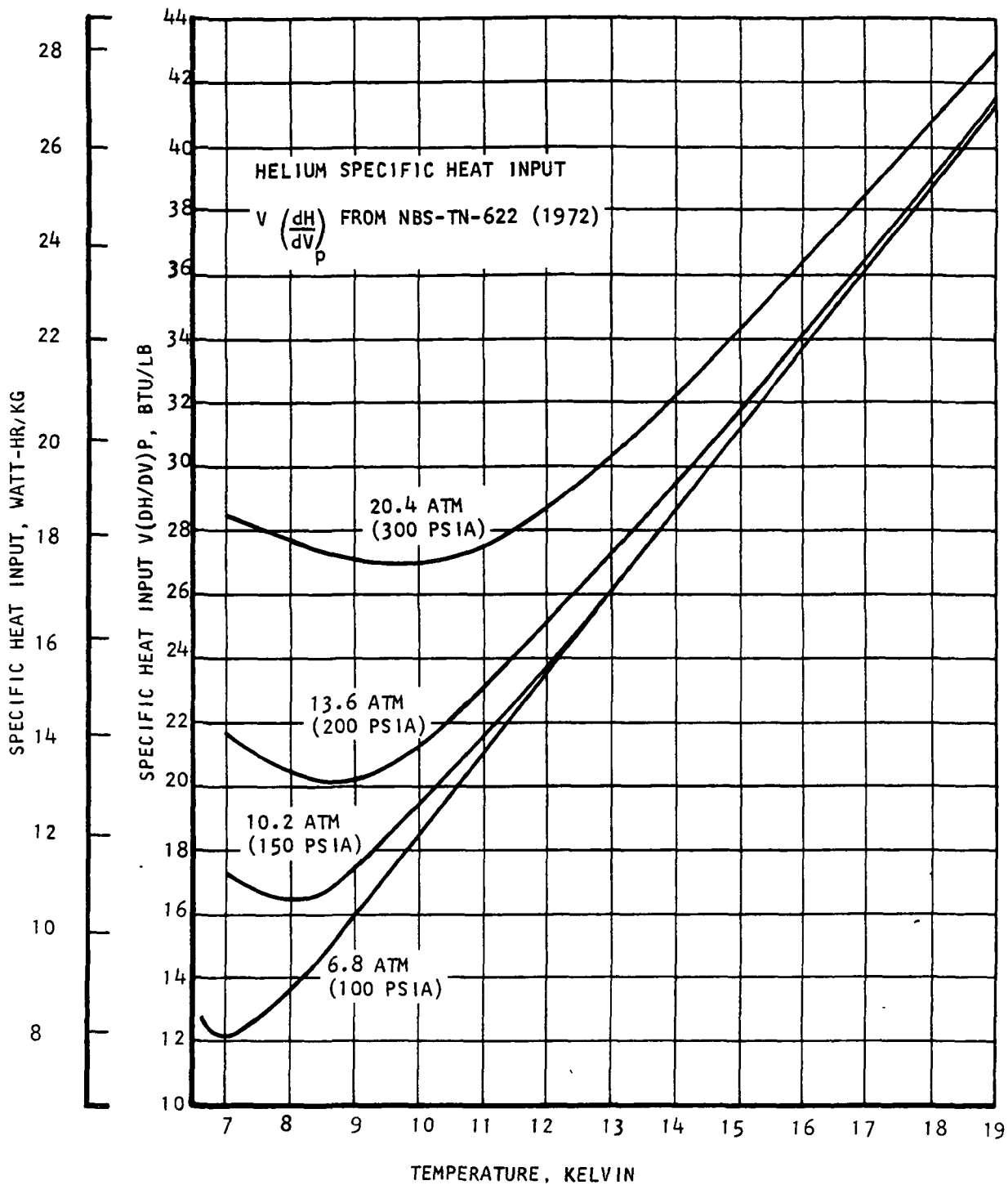
The reasons for using the LM tank are as follows (independent of cost):

- (1) Availability at NASA-JSC, Houston
- (2) Flight qualified for Saturn V launch and lunar landing
- (3) Size and weight are within C-141 telescope mounting flange requirements
- (4) Helium capacity is sufficient for two 8-hour flights per week without refilling
- (5) Pressure vessel proof tested to 155 atm (2274 psia)
- (6) Qualified to shock load of 15 g's



S-10397

Figure 4-10. LM Helium Tank Predicted Vent Rate at Constant Pressure



S-10396

Figure 4-11. Helium Specific Heat Input

- (7) Thermal performance capabilities well-known
- (8) Internal heat exchanger allows flexibility of pressure control

There are only two disadvantages of using the LM tank, as is:

- (1) It does not contain an internal temperature sensor
- (2) Although the fill quick disconnect is excellent for filling, it imposes a relatively high heat leak penalty on the supply interface (the only suitable interface to the optical cavity is with the tank fill line)

However, the first disadvantage is overcome by installing a temperature sensor into the fill line when the interface modification is being performed. The supply interface modification remains as the major task in adapting the LM tank to the ADCS.

MSFC H₂/He Tank

This tank was originally designed to store approximately 565 liters (20 cu ft) of supercritical hydrogen for the U.S. Air Force Manned Orbiting Laboratory (MOL) atmosphere and reactants supply subsystem. Subsequent to MOL program cancellation in June 1969, two of these tanks were fabricated and LH₂-tested under contract with Edwards AFB. Subsequently, NASA-MSFC, Huntsville, contracted to modify the second tank and conduct further testing with LH₂. This program and a summary of the previous test results is documented in AiResearch Report No. 75-11607, "Phase I Final Report, Cryogenic Hydrogen/Helium Storage and Supply System," dated February 3, 1976 (Contract NAS830574). The tank assembly is currently at AiResearch. Among the final modifications of the MSFC tank were the addition of microsphere insulation, and the installation of a separate supply line to feed a J-T cryostat. It is this final modification that makes this tank (technically, that is) a candidate for the ADCS. The special boss allows for a relatively low heat leak transfer path to the JTX.

The details of the MSFC tank will not be repeated here, since they are well covered in the above mentioned report and Drawing 851240.*

Based on the test data obtained from liquid hydrogen testing (the tank was never tested with helium), the insulation characteristics derived were used to perform a heat leak analysis of several possible configurations. Figure 4-12 presents the results graphically. Several different emissivities were used for the aluminized shell surfaces in the tank without microspheres, on the assumption that in removing the microspheres the shells would not be realuminized. It is not expected that the surfaces would be degraded by a factor of 3, however.

* Included in Appendix A.

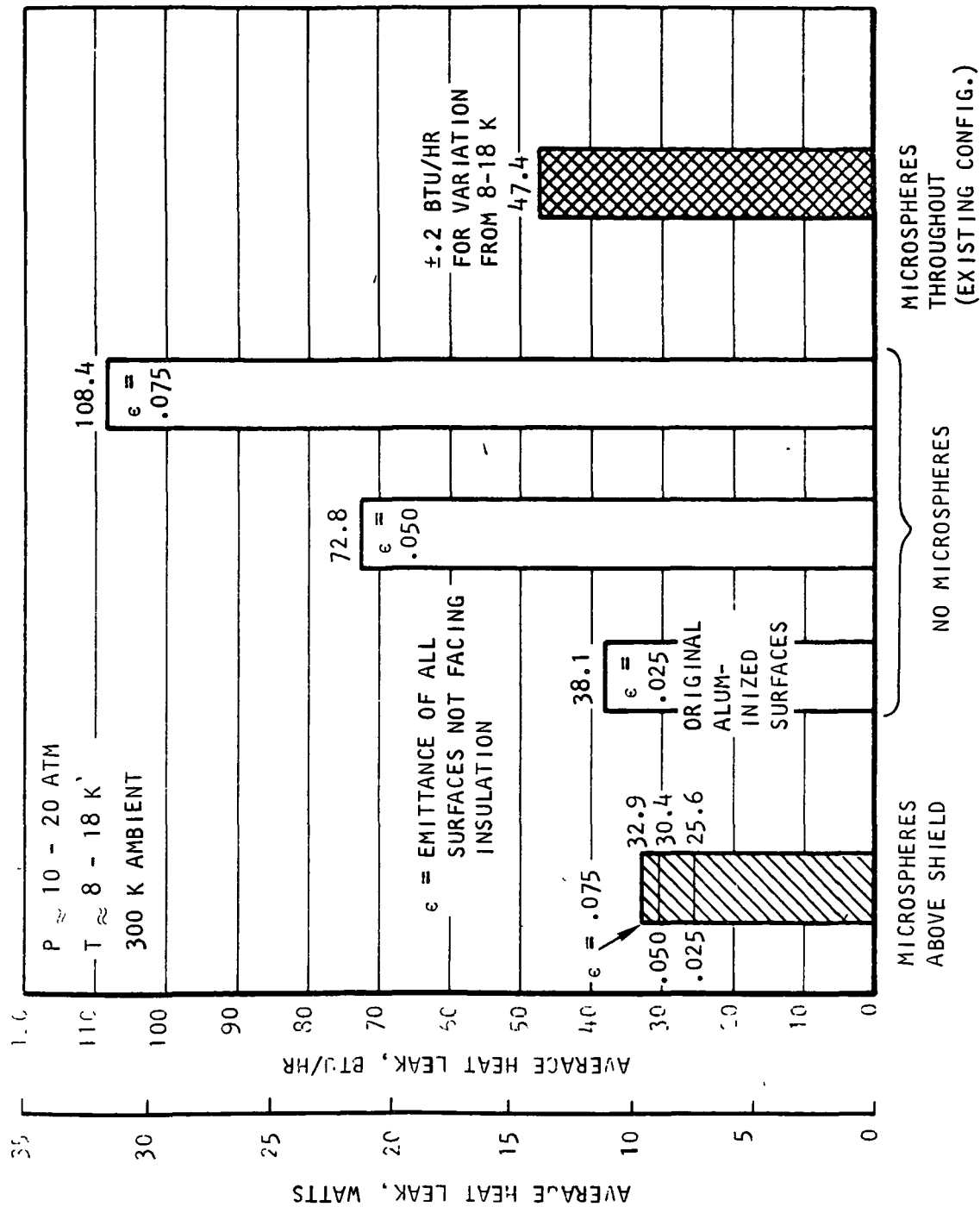


Figure 4-12. MSFC H₂/He Tank Estimated Heat Leak Comparison

5-10/02

Although the MSFC tank does contain a vapor-cooled shield, this study assumed the VCS was bypassed, and all the flow is going directly out the J-T cryostat supply line. These results show that the MSFC tank has a much higher heat leak than the LM tank, about a factor of 6 to 7. This is not to say the MSFC tank is not a high performance tank, because in its original configuration, with flow through the VCS, its heat leak was about the same as the LM tank, while its fluid capacity is over 3 times greater than the LM tank. The high heat leak of the MSFC tank can be used to advantage in the ADCS, however, by providing the relatively high flow rate to the optical cavity at nearly constant pressure without active pressure control. That is, the heat leak alone provides the energy required to maintain pressure. Figure 4-13 is a plot of the estimated vent rate of the MSFC tank as a function of stored fluid temperature at various pressures. These curves imply that ADCS operational parameters would be somewhat different than described earlier. A higher flow rate would be used to operate at similar pressures, or even higher pressures.

The system schematic would be different, also, since the MSFC tank does not contain any internal heating device for pressure control. Figure 4-14 shows an alternate flow schematic that would work with this tank. Pressure control is shown by providing a separate high pressure, ambient temperature, helium storage bottle and regulator. This is probably more economical than a warmup heat exchanger loop with recirculation pump. No system analysis was performed on this option, since it was disregarded for other reasons. The estimated weight of this system, filled with helium, is about 220 kg (485 lb).

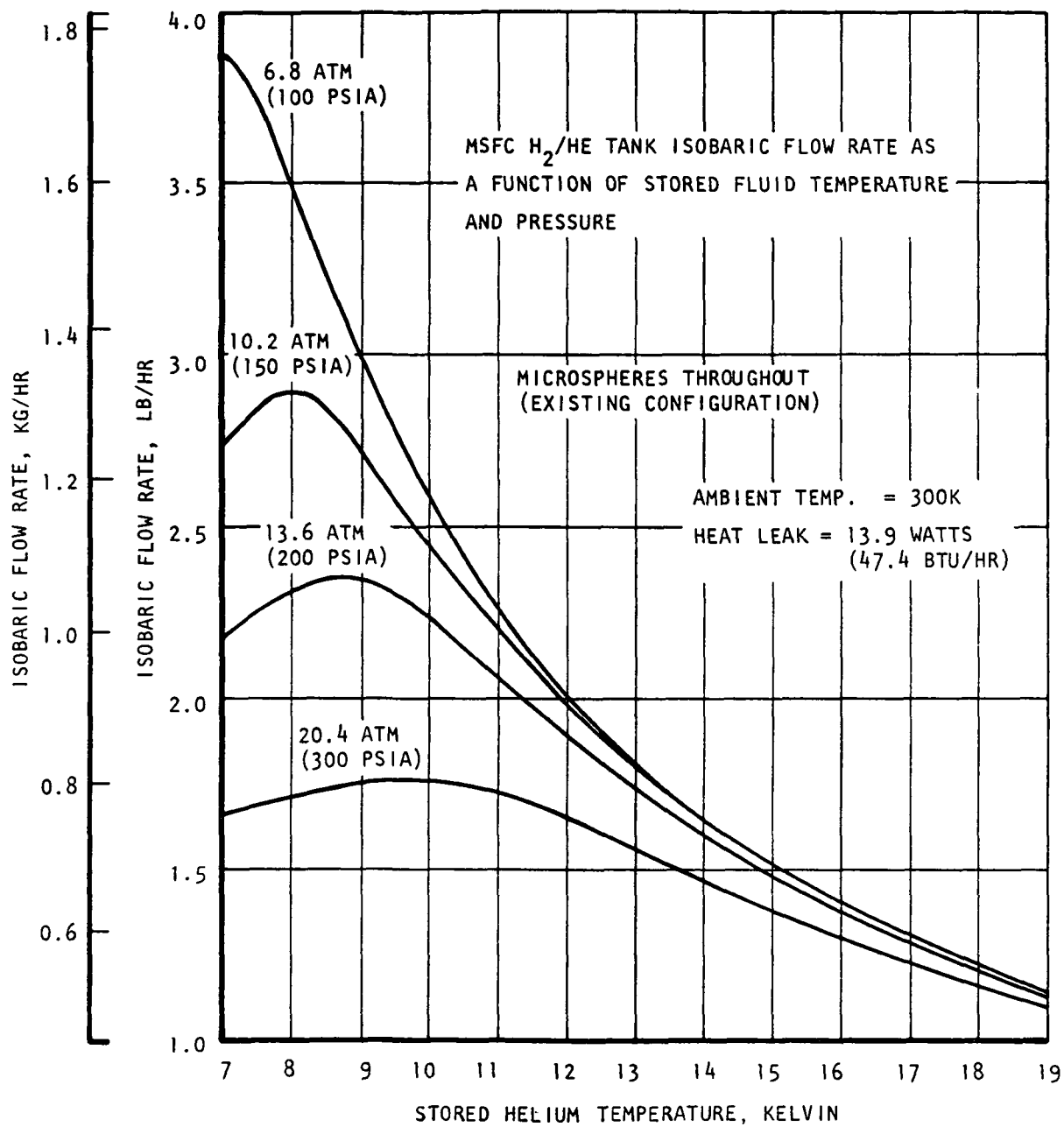
A preliminary stress analysis was performed on the supporting frame, shown in layout drawing L197169*, revealing that several high stress areas have very little margin of safety with a 9-g input load. If this option were seriously considered, a more detailed analysis would be required.

Also checked by a preliminary stress analysis was the load carrying capability of the MSFC tank girth ring, where it attaches to the outer shell. The maximum load that could be supported without yielding is about 5 g, with a tank filled weight of 132 kg (291 lb).

In summary, the only advantages to using the MSFC tank in the ADCS are (independent of cost):

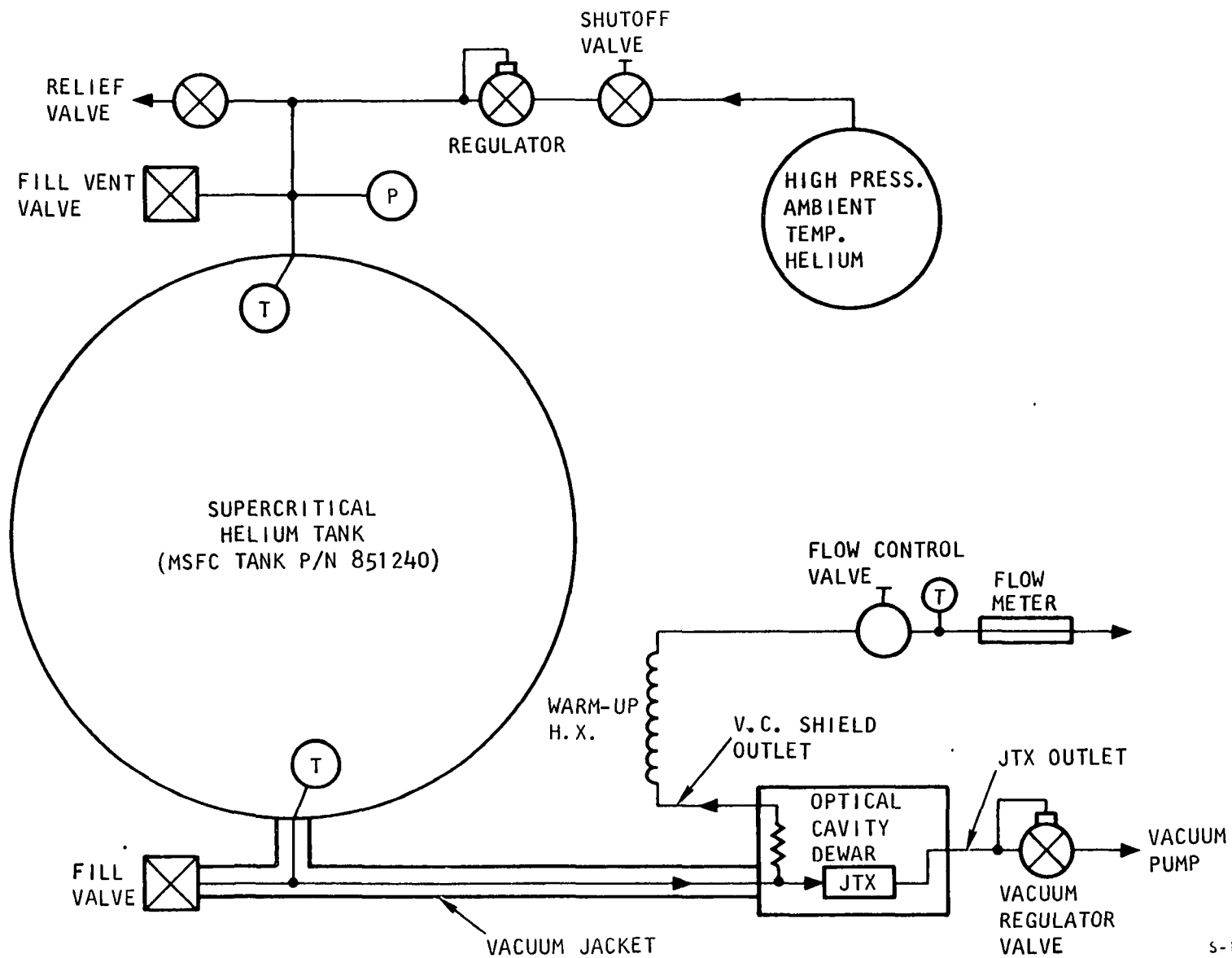
- (1) Availability
- (2) Special supply line built into the tank to interface with optical cavity dewar
- (3) Several temperature sensors installed in pressure vessel
- (4) The thermal performance capabilities (to LH₂ temperature) are quite well-known

* Included in Appendix A.



S-10398

Figure 4-13. MSFC H₂/He Tank Predicted Vent Rate at Constant Pressure



S-10435

Figure 4-14. Alternate ADCS Flow Schematic (MSFC H₂/He Tank)

The disadvantages, and reasons for not recommending the MSFC tank for the ADCS are:

- (1) Too large: overcapacity (565 liters vs 167 liter LM tank), and overweight (tank with frame and components would weigh about 220 kg, the limit on telescope flange is 182 kg)
- (2) Girth ring may not withstand 9-g impact load
- (3) No internal heating device, must provide external pressurant or recirculation loop
- (4) Supply interface has to be modified to connect with transfer line to JTX, although this task is also required with LM tank
- (5) Never tested with helium
- (6) Not flight qualified; never vibration or shock tested

Commercial Dewar

Bids were solicited from several commercial dewar manufacturers for a helium tank capable of meeting an 8 hr mission. The problem statement was based on supplying the optical cavity dewar with 10.2 atm (150 psia) helium at a maximum temperature of 18 K, and a flow rate of 0.454 kg/hr (1.0 lb/hr). If the connector warmup is limited to 3 to 4 K, this mission could be accomplished with a 47-liter-capacity dewar. A hold time of 24 hr was also specified. For full-tank pressure buildup from 10.2 atm to 13.6 atm (200 psia) in 24 hr, the dewar heat leak has to be less than 0.16 watt (0.55 Btu/hr).

Cryolab, of San Osos, California, proposed to build a supercritical helium delivery system to satisfy these requirements, including a demonstration prior to acceptance. The dewar and supports will be designed to satisfy the 9-g crash load requirement. The spherical dewar stores 5.9 kg (13 lb) of helium in a 45 cm (17.7 in.) I.D. pressure vessel, within a 55 cm (21.7 in.) diameter vacuum shell. The dewar, complete with internal pressure controller, fill, vent, and relief valves, burst disc, pressure and temperature sensors, would weigh about 23 kg (50 lb) dry. Together with a support frame the total estimated filled weight is about 40 kg (88 lb), well within the telescope flange limit.

TANK/OPTICAL CAVITY INTERFACE

The interface between the helium tank and the optical cavity dewar requires thoughtful attention in order to minimize warmup of the JTX supply stream. A high transfer heat leak means higher inlet temperature, which decreases the operating time of the system. Transfer warmup also determines the degree of utilization of the stored helium, that is, higher warmup means higher residual density (quantity) in the tank. Layout drawings L197168* and L197169* each show a detail of the tank supply line modifications to provide vacuum-jacketed transfer of helium to the optical cavity. In addition, Drawing

* Included in Appendix A.

900155* shows additional details of the folded-bayonet design of the tank fill boss. In both cases the bayonet design provides a low-conduction, passive radiation-shielded, metal-to-metal joint to separate the tank annulus vacuum from the optical cavity vacuum (which will be common with the transfer line vacuum). This separation is required so that the optical cavity dewar can be opened repeatedly, without having to reprocess the tank annulus.

The LM tank connection has an unavoidable additional source of heat leak from the fill quick disconnect. A detailed thermal analysis (24 nodes) of this component was performed, and the estimated heat input to the elbow was about 1.0 watt (3.5 Btu/hr). A detailed thermal analyzer model of the entire connection was established, consisting of 31 metal nodes and 14 fluid nodes. The fluid nodes allowed the program to calculate the helium outlet (JTX inlet) temperature as a function of flow rate and inlet (tank) temperature. Helium properties at 13.6 atm (200 psia) were used. At the elbow node, a heat generation rate was input to simulate the thermal effect of the quick disconnect.

Figure 4-15 presents the results of the LM tank connection outlet temperature plotted as a function of inlet temperature for several flow rates. This plot shows that helium warmup through the connection is nearly constant over the inlet temperature range studied. A breakdown of the heat leak for this range of flows and temperatures averaged: 43 percent for quick disconnect conduction, 36 percent for radiation from the vacuum jacket, and 21 percent for sleeve conduction in the bayonet section at the tank end. The overall heat leak results ranged from 2.18 to 2.24 watts (7.45 to 7.65 Btu/hr).

Figure 4-16 presents the estimated performance of the MSFC tank connection, based on a thermal analyzer model with 33 metal nodes and 11 fluid nodes. In this case the overall heat leak averaged about 1.06 watts (3.62 Btu/hr), or slightly less than half that of the LM tank interface, and was almost equally split between sleeve conduction and vacuum jacket radiation. The difference between the LM tank and MSFC tank connections is almost entirely due to the presence of the fill quick disconnect on the LM tank.

Figure 4-15 was used in the system analysis (Table 3-1 and Figure 3-2) to determine the JTX inlet temperature from the tank temperature and flow rate.

The commercial dewar interface will be an open-ended vacuum-jacketed line of length approximately equal to the LM tank connection, the inner tube being sufficiently long to reach to the fitting at the inlet of the optical cavity. The manufacturer shall demonstrate by testing a transfer line heat leak of 2.5 watts, or less.

. FLEXIBLE TRANSFER LINE

The ADCS specification states that "a flexible transfer line of 8 feet minimum length shall be primarily designed". This requirement would be important if the optical cavity dewar were mounted in the direct-Cassegrain configuration.

* Included in Appendix A.

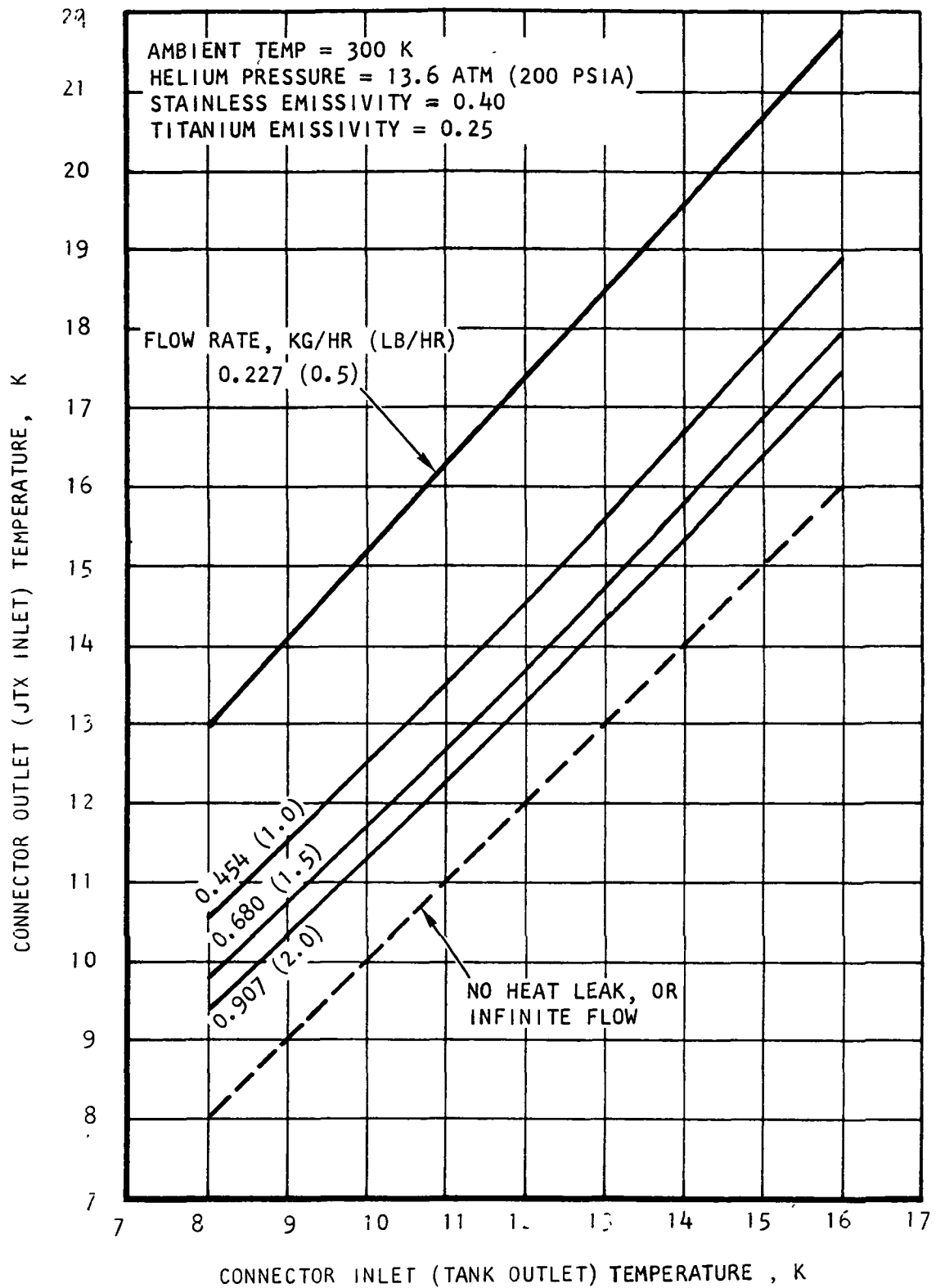


Figure 4-15. Performance of LM Tank Connection to JTX Optical Cavity Dewar

S-10431

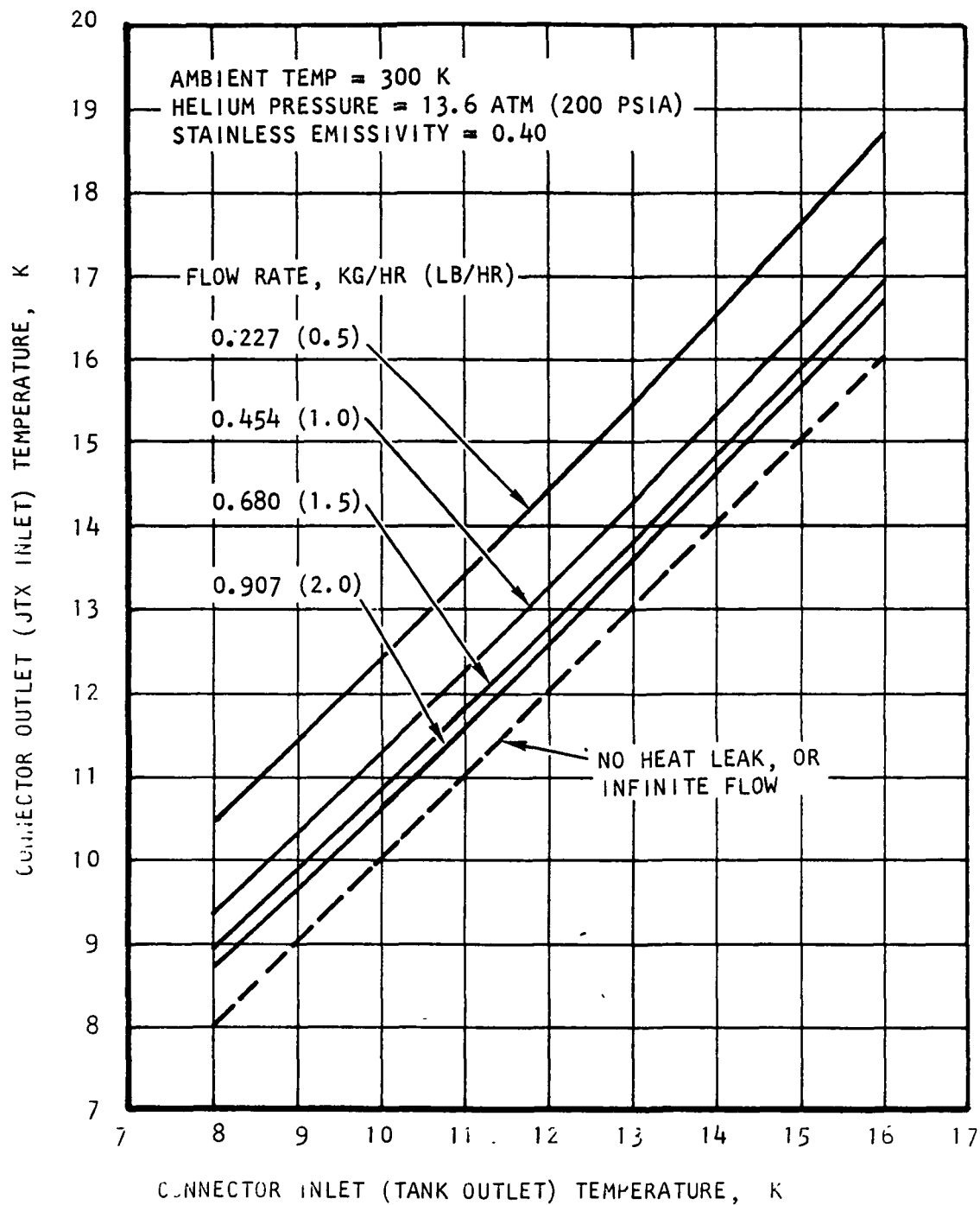


Figure 4-16. Performance of MSFC Tank Connection to JTX Optical Cavity Dewar

S-10432

Since the present system is designed for the bent-Cassegrain configuration, it can be mounted on the cabin-side instrument flange as a single unit, with the cavity dewar rigidly connected to the helium tank.

A brief study was performed to determine the effect of various rigid vacuum-jacketed lines on warmup of the helium supply. This study assumes that a standard vacuum-jacketed connector is no better than the 10 cm (4 in.) double-sleeve bayonet section of the MSFC tank interface (L197169)*, namely 0.57 watt (1.96 Btu/hr) per connector. The vacuum jacket is assumed to be stainless steel (emissivity = 0.40), and a flow rate of 0.454 kg/hr (1.0 lb/hr) is used to calculate the warmup temperature difference. Table 4-4 summarizes this brief study, for 8 feet of line, with 0.476 cm (3/16 in.) diameter inside tube and 1.588 cm (5/8 in.) diameter vacuum jacket (without supports).

TABLE 4-4
ESTIMATED PERFORMANCE OF 8 FT TRANSFER LINE
AND CONNECTORS

Insulation System	Heat Leak (Watts)	Temperature Rise (K)
Vacuum, only	6.68	8.7
Micro Quartz Felt (0.1 g/cc)	5.58	7.4
Superinsulation	1.85	2.4

To achieve a temperature rise comparable to that in the LM tank interface would require superinsulation. Vapor-cooling would reduce the heat leak significantly, but the design and installation would be much more complex and costly, particularly in the connectors.

JTX SUPPLY GAS CONDITIONER

A gas conditioner is required to provide a constant temperature and pressure helium supply to the JTX under varying helium storage conditions. Constant pressure is maintained by controlling the tank pressure as shown in the system schematic (Figure 3-1). The inlet temperature is controlled by a heater-temperature controller connected to an electrically-heated heat exchanger. This heat exchanger is simply a 1.22 m (4 ft) length of heater wire 0.0889 mm (0.0035 in.) in diameter (over insulation) wound around the JTX supply line. On the 0.238 cm (3/32 in.) O.D. supply line, this tightly-wound coil of wire covers a length of only 1.42 cm (0.56 in.).

A preliminary heat transfer analysis of this heater was performed to determine the power required and effectiveness of the heat exchanger. The maximum heat input required was estimated to be 1 watt. This power will heat a stream of 13.6 atm (200 psia) helium flowing at 0.054 kg/hr (0.12 lb/hr)

from 7.2 K to 16.7 K. The heat transfer effectiveness was such that the heater wire temperature need not exceed approximately 125 K, in order to transfer 1 watt into the helium stream.

Commercial equipment is available to accomplish the required temperature control. Lake Shore Cryotronics, Inc., Eden, N.Y., will supply the heater wire, Catalog No. NM-36; two silicon diode temperature sensors (Model DT-500P-GR-MIN/1), one for heater control and one for independent temperature measurement; and a Model DTC-500 Precision Cryogenic Temperature Indicator/Controller. The temperature sensors will be calibrated over the range of 4.2 K to 40 K.

OPTICAL CAVITY TEMPERATURE CONTROLLER

This component, more appropriately termed the JTX load (detector) temperature controller (since the bulk of the optical cavity, including the cold plate, will be controlled by the VCS temperature and cooling rate), is required to allow for detector temperatures higher than those normally produced by the JTX. It consists of a heater wire coiled around the JTX sheath adjacent to the detector flange. In addition to the heater/controller temperature sensor, an independent temperature sensor is mounted on the detector plate, as this is the temperature which the controller must stabilize.

The heater power required to warm the expanded helium from 2 K to 6 K at the 13.6 atm operating condition is approximately 0.5 watt.

Lake Shore Cryotronics will supply the same equipment for this controller as for the JTX inlet temperature controller. The temperature sensors will be calibrated over the range of 1.5 K to 40 K.

JTX DISCHARGE PRESSURE CONTROLLER

The control of the pressure at the discharge end of the JTX is to be accomplished with a precision adjustable vacuum regulator valve. This valve will operate in the 2 - 20 torr (mm Hg) range for typical JTX operation. The mass flow rate could be as high as 0.068 kg/hr (0.15 lb/hr).

Lake Shore Cryotronics Vacuum Regulator Valve, Model 346, satisfies this requirement.

VACUUM PUMP

The requirements for two vacuum pumps are to be identified. The optical cavity dewar evacuation can be performed by either of the two pumps available on the C-141 aircraft. The JTX discharge vacuum requirements exceed the capability of those pumps. A vacuum of 2 torr with helium flow of 0.045 kg/hr (0.10 lb/hr) requires a pump capacity of about 1800 liters/min. The Welch 1397 on board the C-141 has a 500 liter/min capacity.

OTHER COMPONENTS

Other commercially available equipment is listed in Table 4-5, as it applies to either the LM tank (L), or the MSFC tank (M), or the commercial dewar (C).

TABLE 4-5
OTHER COMMERCIAL COMPONENTS

Part Name	Application*	Description
Pressure Control Valve	L	Circle Seal 3-way Solenoid SV10A32P4T
Flow Control Valve	L, M, C	Hoke 4112G4Y
Flowmeter	L, M, C	Fischer Porter 10A3500 (0-2 lb/hr)
Relief Valve	L, M	Circle Seal 5120T-2M-200 (200 psig)
Burst Disc	L, M	Wintec/BS&B
Fill Valve	M	Hoke 4172G4Y
Vent Valve	M	Hoke 4172G4Y
Tank Pressure Sensor	L, M	PLC-300-G2 (0-300 psig)
Tank Temperature Sensor	L	Lake Shore Cryotronics DT-500P-GR-MIN/I
Warmup Heat Exchanger	L, M	Voss Finned Tube, Miniature Series
Pressurant System	M	TAVCO, 2300 cu. in., 17 in. O.D., 3000 psig, with Regulator, Shutoff Valve, Gage and Burst Disc

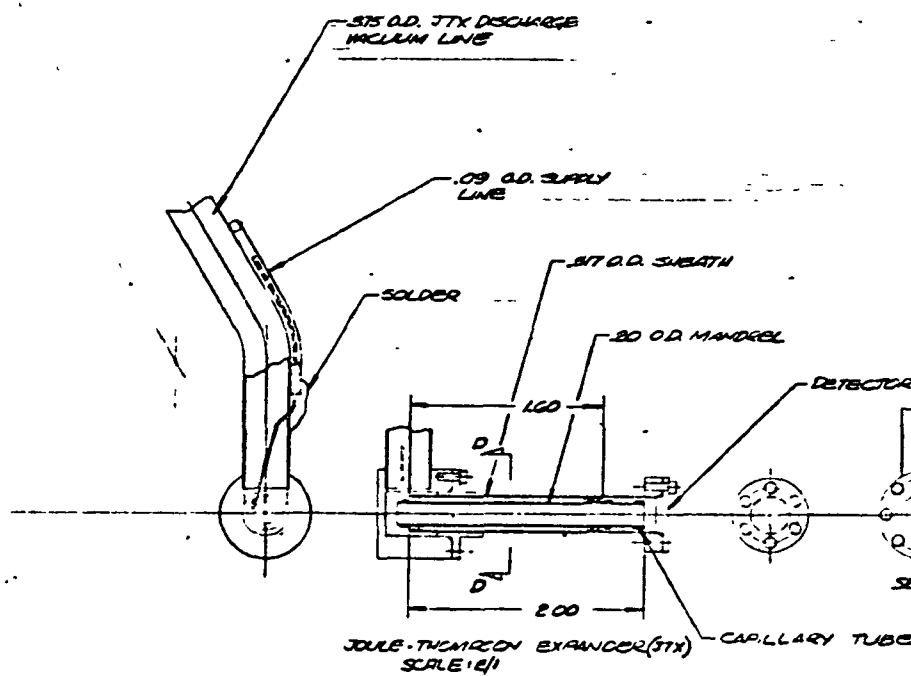
*Application:

L = LM Tank
M = MSFC Tank
C = Commercial Dewar

APPENDIX A
DRAWINGS

FRAME

REPRODUCIBLE
ORIGINAL PA



Joule-Thomson Expander (JTX)
SCALE 1/2/1

DETECTOR

CAPILLARY TUBE

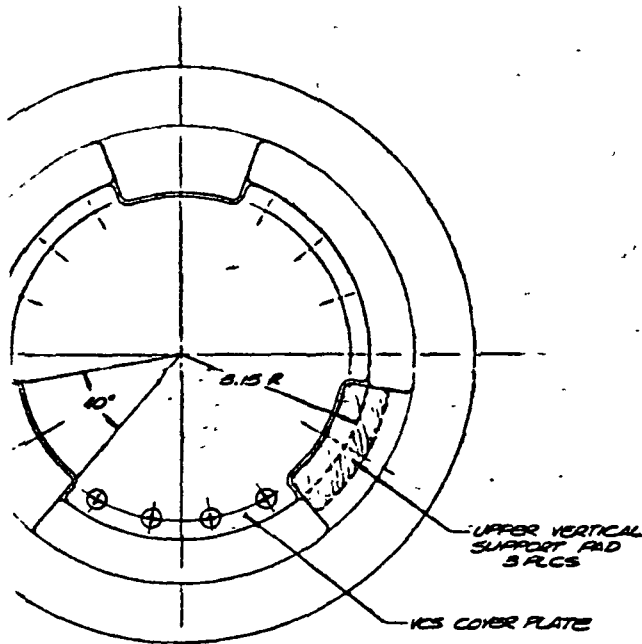
20 O.D. MANDREL

.87 O.D. SWEATH

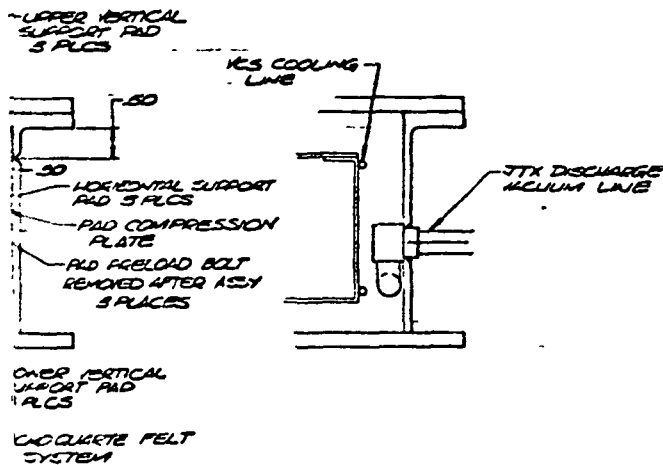
SOLDER

.09 O.D. SUPPLY
LINE

575 O.D. JTX DISCHARGE
MEDIUM LINE



SEC B/B
TOP VIEW KCS COVER PLATE
AND SUPPORT PADS



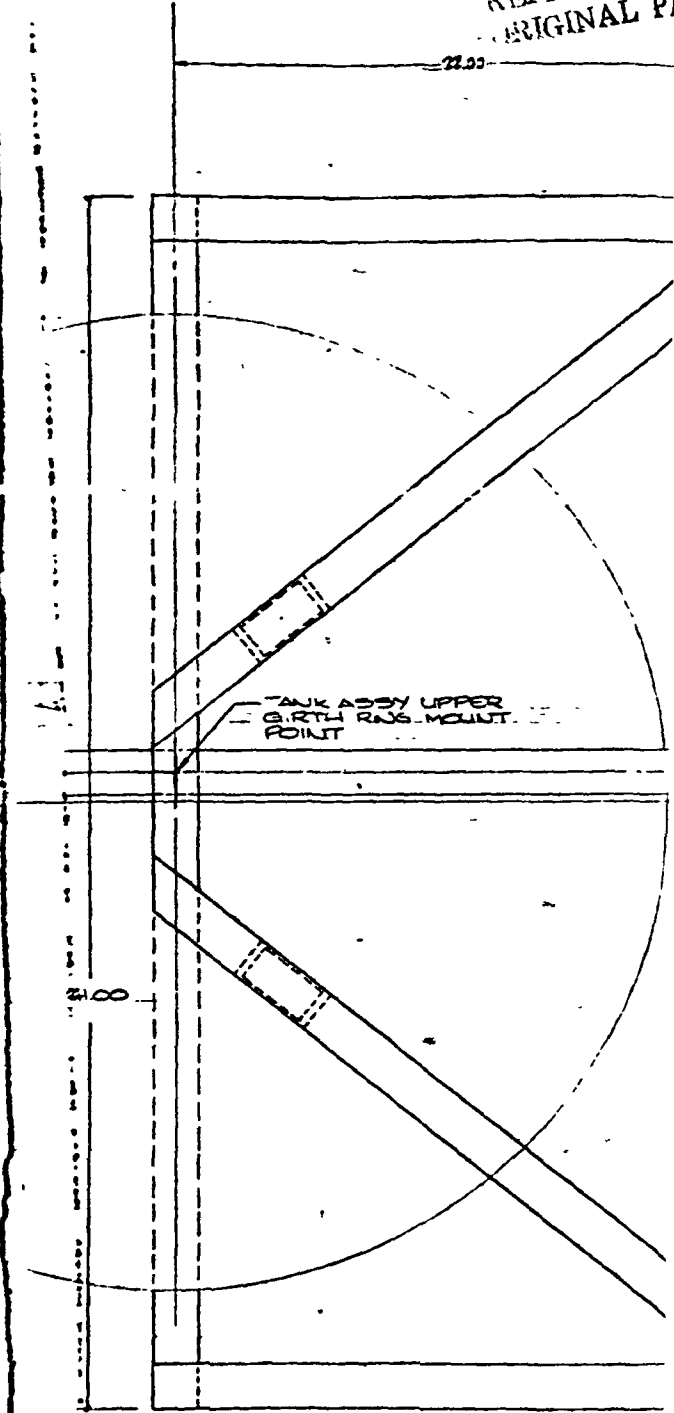
ALL DIMENSIONS NOMINAL (INCHES).
NOTES: UNLESS OTHERWISE SPECIFIED

<div> </div>				DONOR'S PROPERTY U.S. GOVERNMENT PROPERTY	
DATE: BY: FOR: PART: QUANTITY: UNIT: REMARKS:				OPTICAL CAVITY DEWAR	
SCALE: DT: SHEET: OF:				70210 L 197157	
FEATURES:				ER 2446	

FOLDOUT FRAME

REPRODUCIBLE
ORIGINAL P/

21.25



TANK ASSY UPPER
BIRTH RING MOUNT
POINT

21.00

VIEW 5.0A
TOP VIEW

ILITY OF THE
AGE IS POOR

900152-6-1 LUNAR
MODULE HELIUM TANK
180 LBS. MAX. (FILLED)

39.00
FOLDOUT FRAME 2

15.70

36.20

FORWARD GIRTH RING
MOUNTING POINT

NOTE: THESE OUTER
SURFACES OF TANK TO
REMAIN COVERED BY
EXISTING FIBERGLASS
REINFORCED SHIPPING
COVERS TO PREVENT OUTER
SHELL DAMAGE

LOWER GIRTH RING
MOUNTING POINT

3.00 MAX
(REF)

MOUNTING
1.50 SO.
WALL MA

PRESS COU
EXCHANGER
EXCHANGER
ENVELOPE

EXISTING SUPPLY
LINE TO WARMUP
HEAT EXCHANGER

C-141 TELESCOPE RANGE (REF)

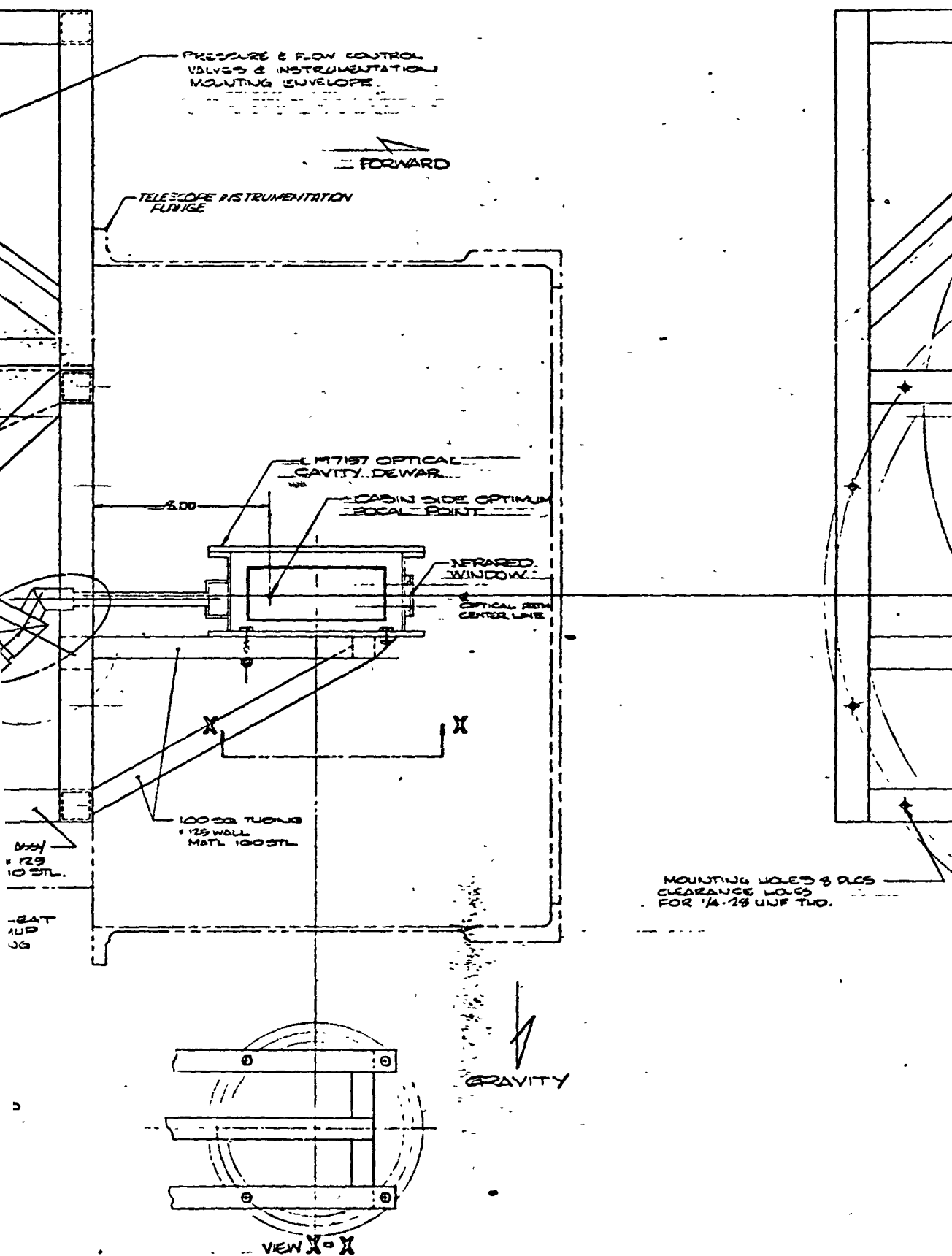
TANK FILL
SUPPLY TUBE
.375 O.D.

3/16 O.D. SUPPLY
OPTICAL CAVITY DEW

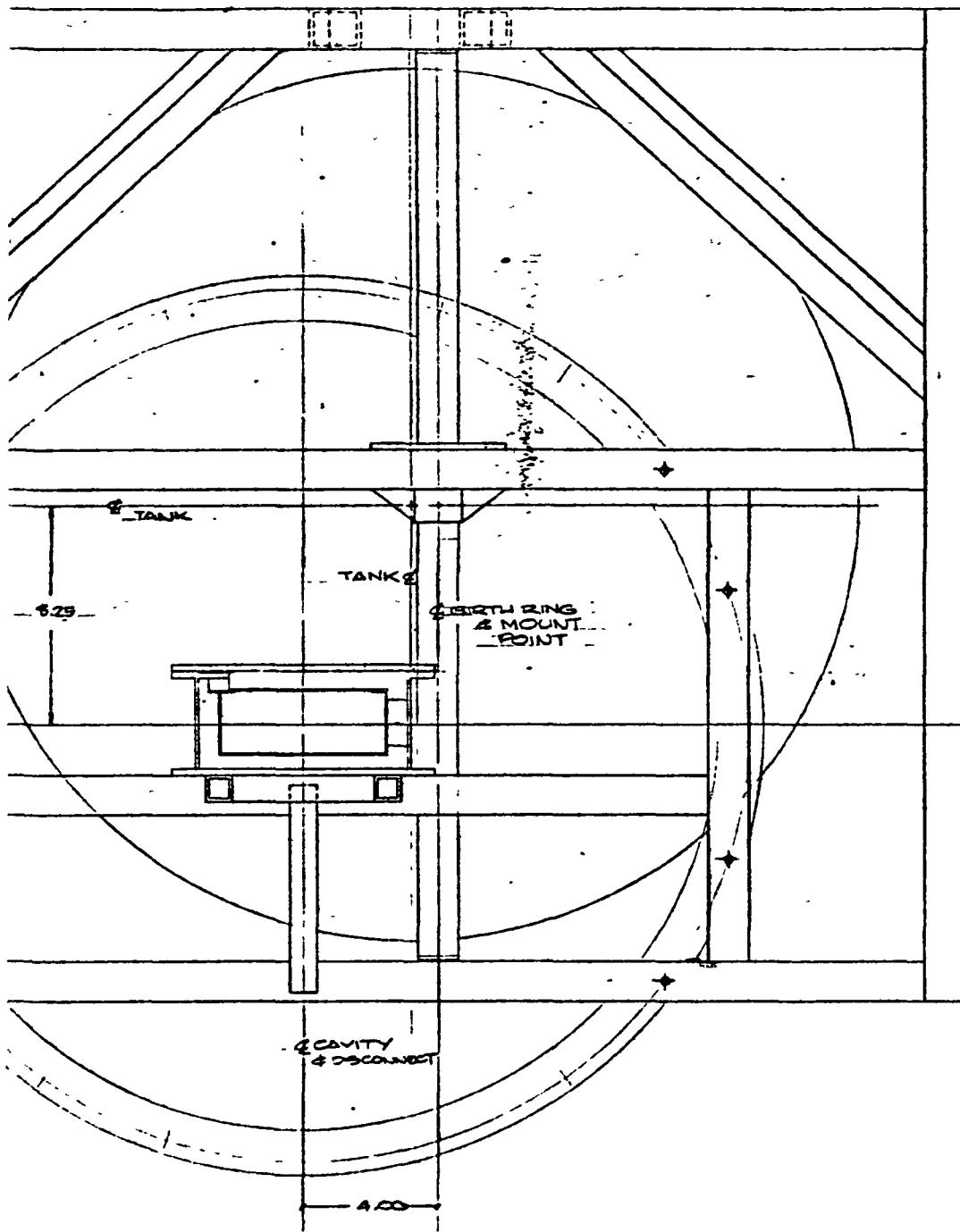
SUPPLY LINE VACUUM JACKET
COMMON WITH OPTICAL CAVITY DEWAR

FILL QUICK DISCONNECT
TANK HALF

MODIFICATION TO EXISTING
TANK SUPPLY LINE
SEE DWS 900 33 FOR
DETAIL OF EXISTING DESIGN



FRAME 3



2. SEE DWG 900155 FOR ADDITIONAL
DETAIL OF EXISTING LM TANK CONFIG.
1. ALL DIMS. ARE NOMINAL (INCHES)
NOTES-UNLESS OTHERWISE SPECIFIED.

DEPARTMENT OF DEFENSE OFFICE OF THE SECRETARY OF DEFENSE WASHINGTON, D.C. 20301-1000			
1577-1			
OPTICAL CAVITY DEWAR LM HELIUM TANK INSTALLATION			
J 70210	L 197168	SCALE 1/2" = 1'-0"	
SHEET 1 OF 1		CR 2416	

MICROSPHER
ACCUMUL

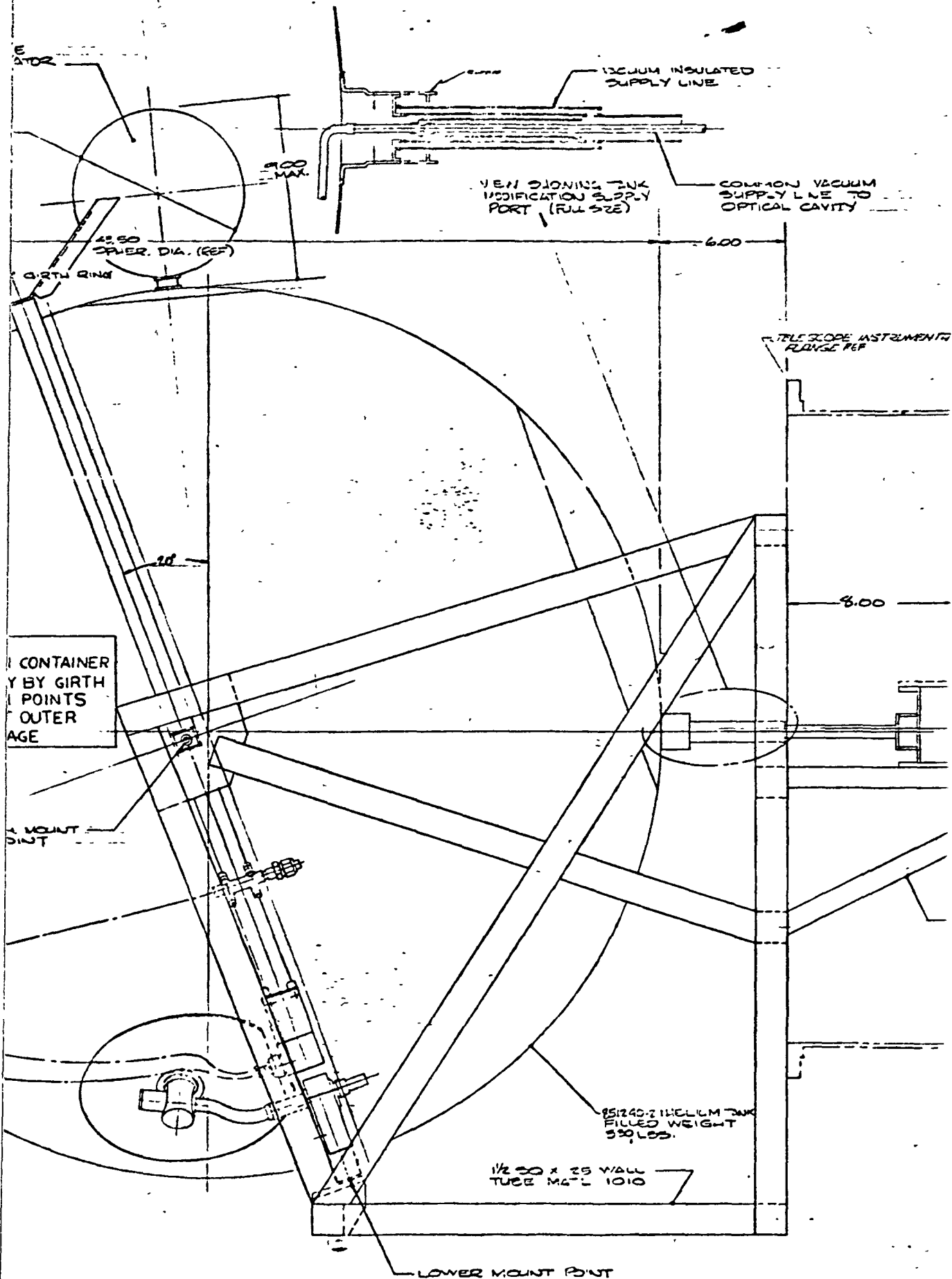
POLEMAN FRAME 1

- 300 DA

CAUTION:
HIGH VACUUM
HANDLE ONLY
RING ATTACH
TO PREVENT
SHELL DAM.

FOAM INSULATED COVER

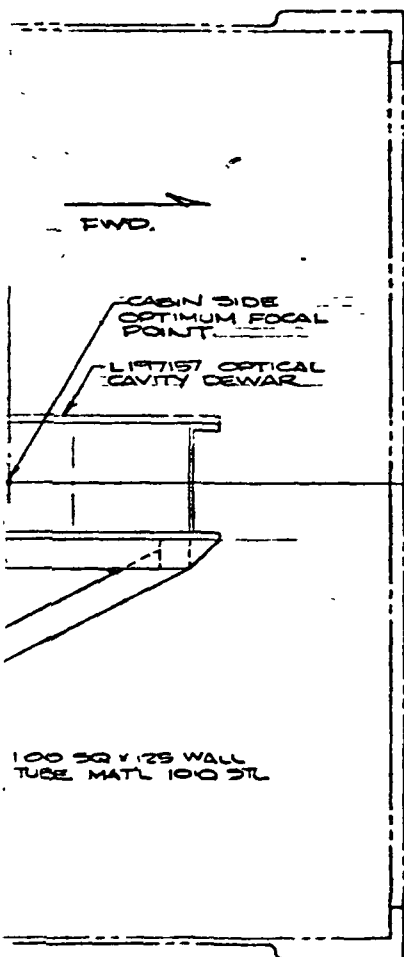
REPRODUCIBILITY
ORIGINAL PAGE 15



OF THE
 S POOP

SIDE VIEW
 LOOKING TOWARD LEFT
 SIDE OF C141 AIRCRAFT

POLOUT FRAME 2

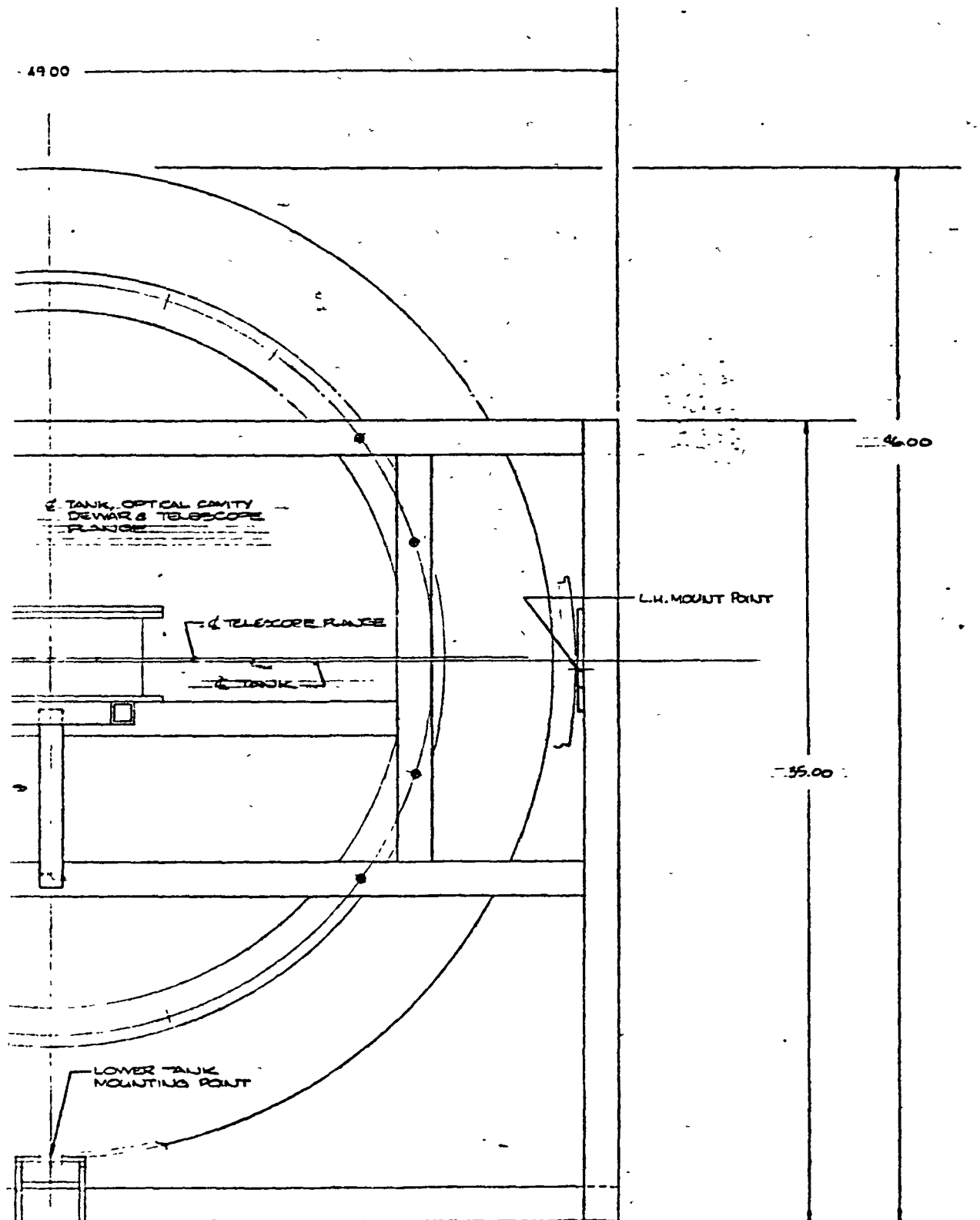


RHE MOUNT POINT

TELESCOPE FLANGE
MOUNTING HOLES & RC
CLEARANCE HOLES FOR
1/4-28 UNF THREAD

VIEW L
FROM T

OUTOUT FRAME 3.



DOING APT
EUSCOPE.

ALL DIMS. ARE NOMINAL (INCHES)
NOTES UNLESS OTHERWISE SPECIFIED

RESEARCH MANUFACTURING CO. COMPANY OF CALIFORNIA 1000 N. 10TH ST. LOS ANGELES 12, CALIF.			
ITEM			
QUANTITY	DATE	BY	APPROVED BY
1	1/1/69	W. J. B. J.	W. J. B. J.
MTC HE/1 e THERMAL TEST TANK INSTALL. FOR OPT. CAVITY DEWAR STD			
70210		L197169	
DATE		BY	
1/1/69		W. J. B. J.	

ER 2496

BOLDOUT FRAME

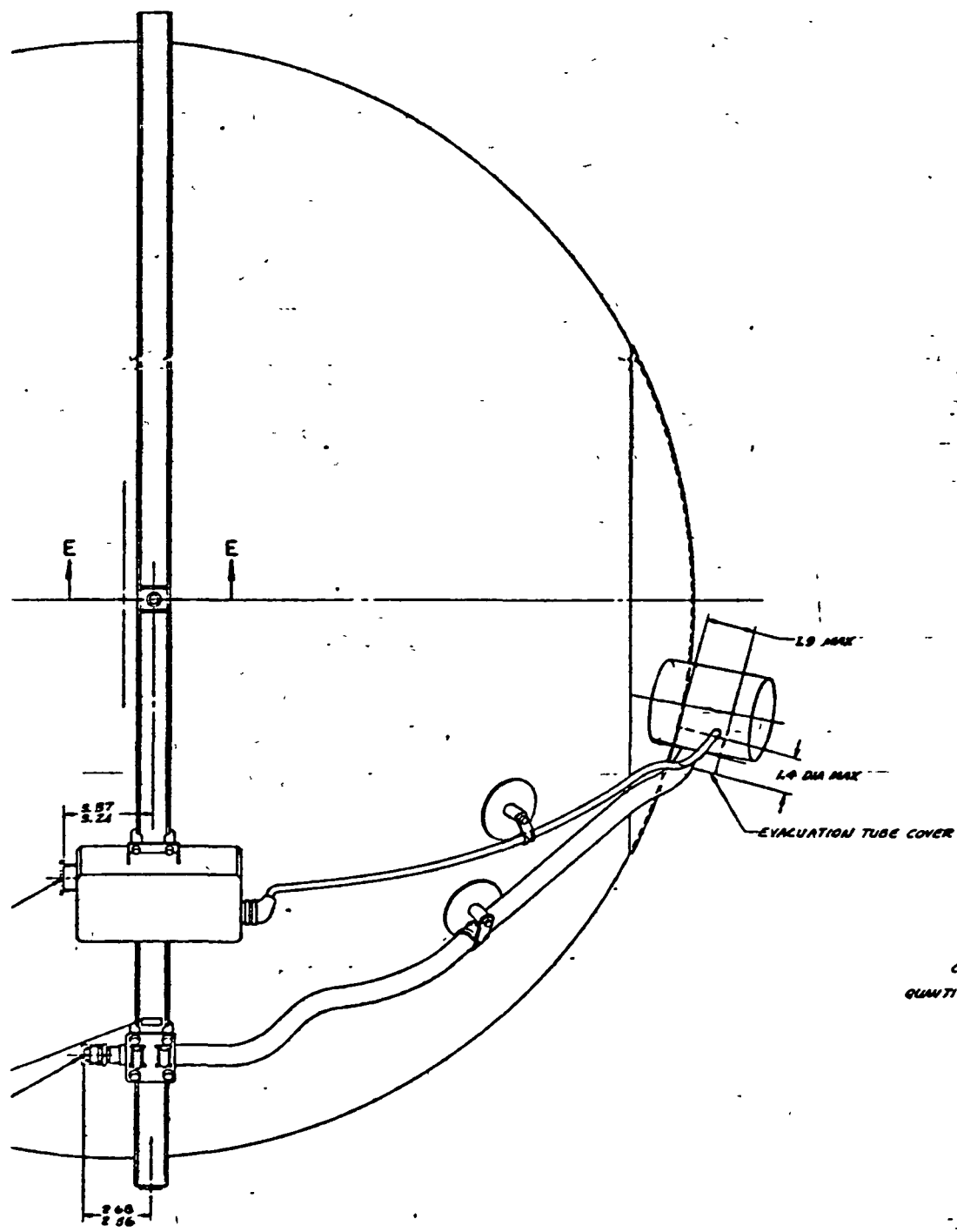
QUANTITY SIGNAL CONDITIONER
RECEPTACLE TO MATE WITH
MS 3116-M-133 PLUG

FILL

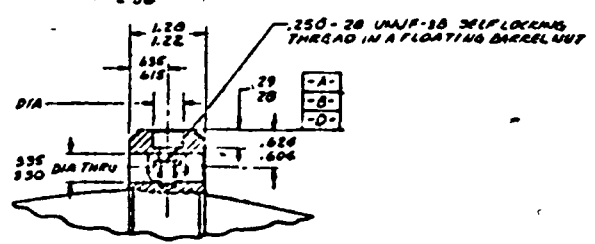
FILL PORT
PER MS35656-6

1A	002	3006
1B	002	4996
1D	002	

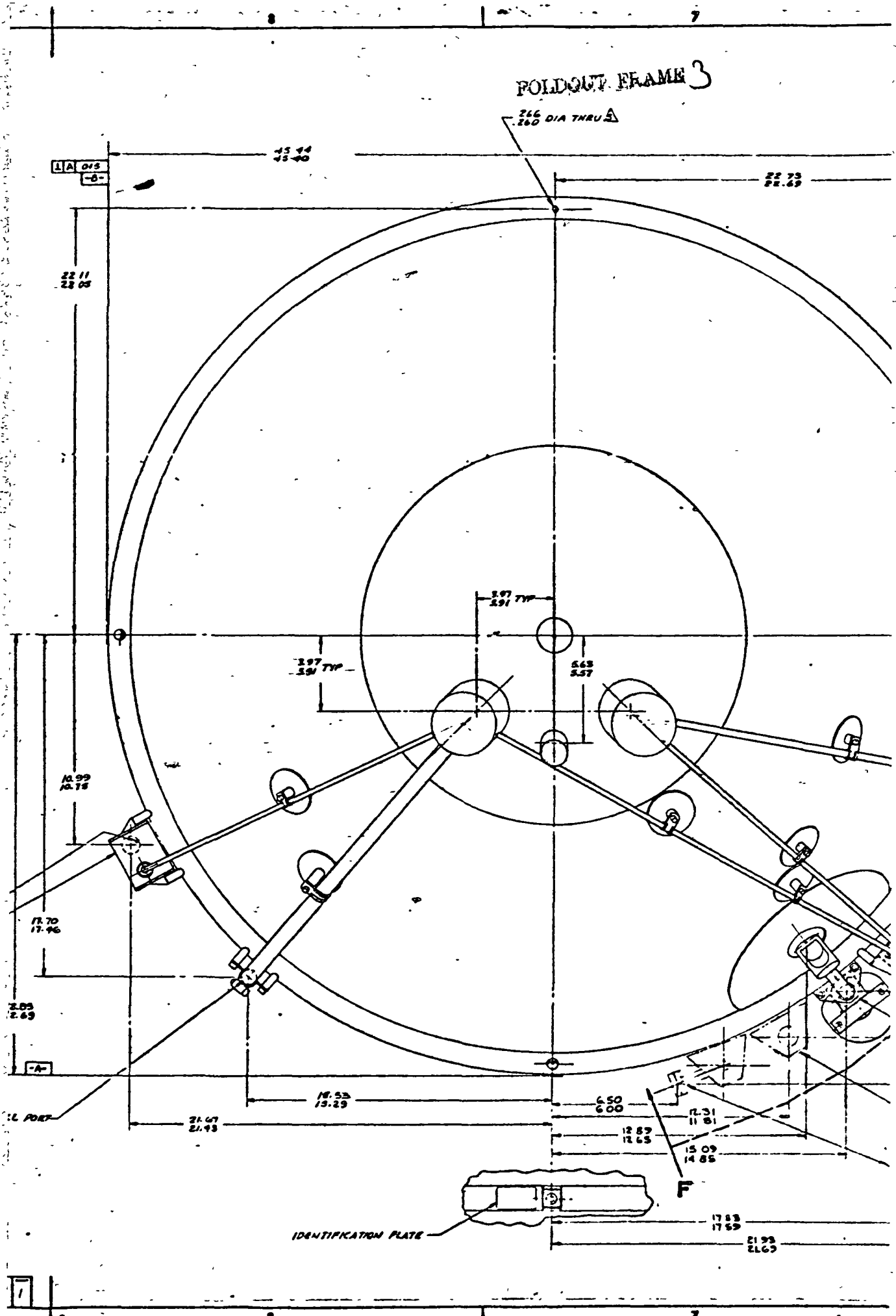
OLGCEY FRAME 2

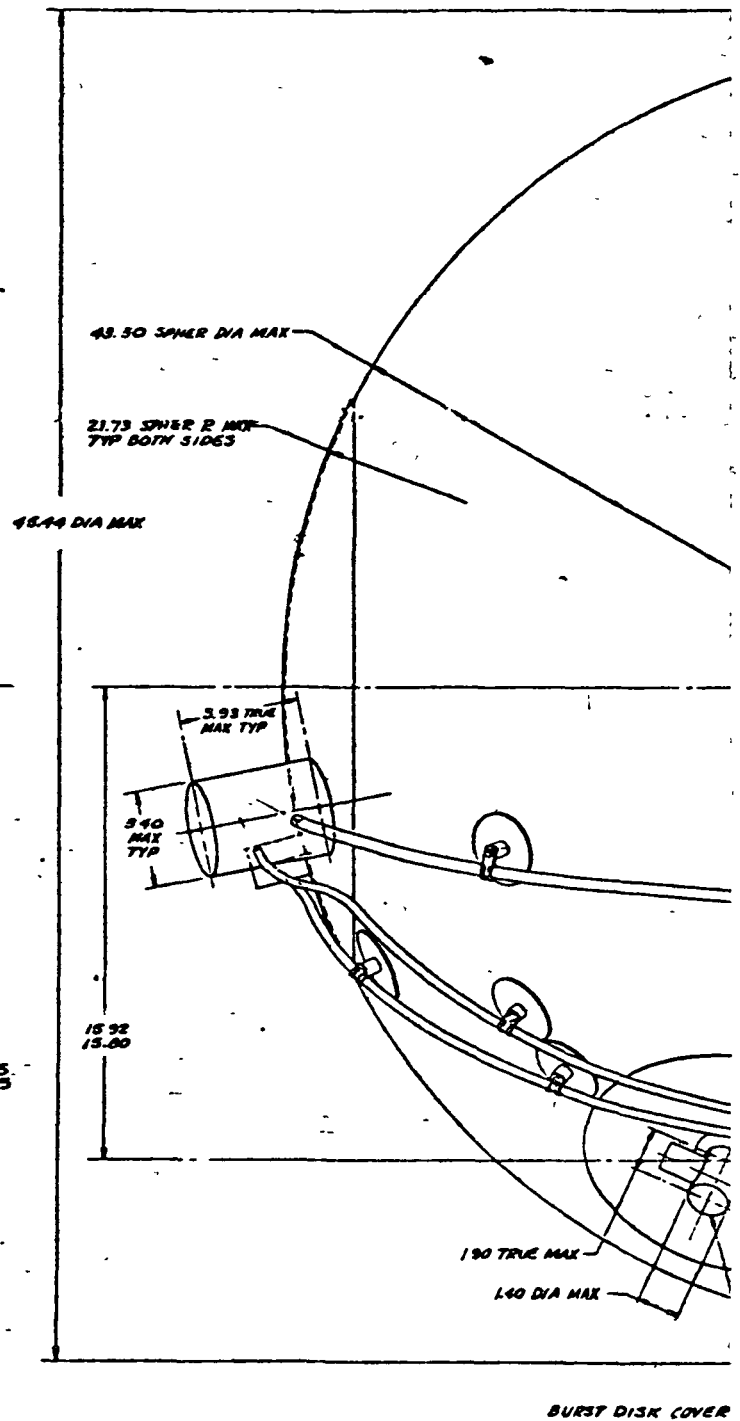
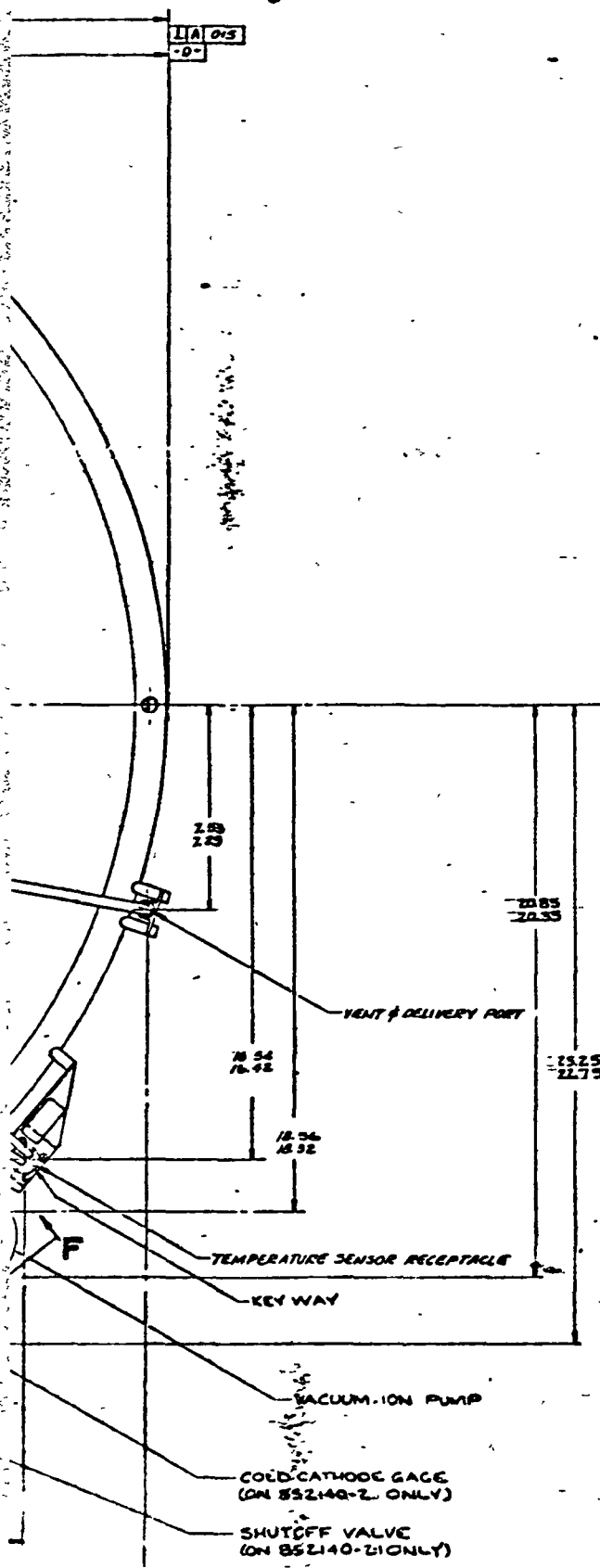


CONNECTOR KEYWAY (REF)
QUANTITY SIGNAL CONDITIONER



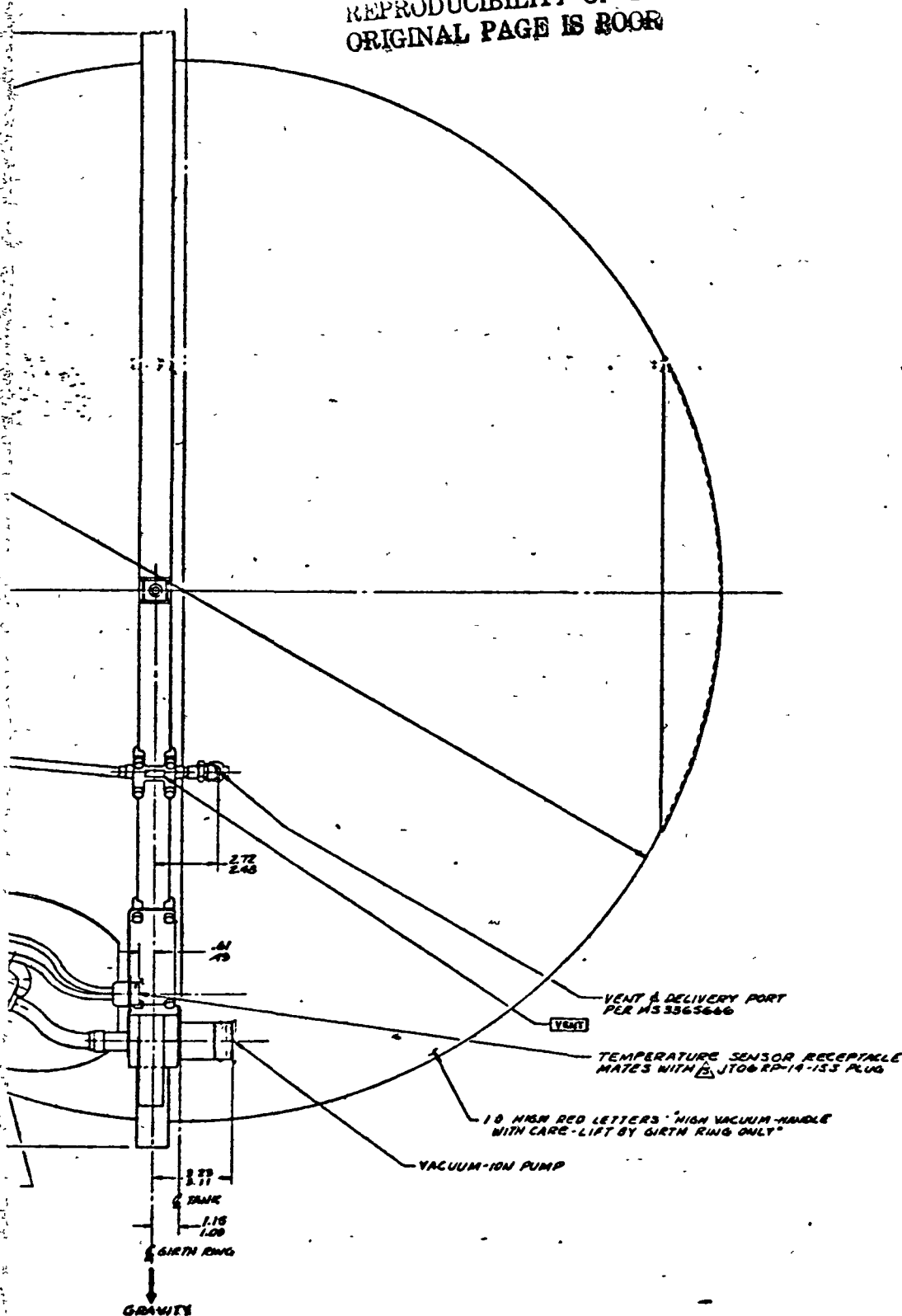
PARTIAL SECTION E-E SCALE 1/4
TYPICAL 3 PLACES





PODDOUT FRAME 4

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR



ALTERED MINI CONFLAT FL.
954-5136 (VARIAN)
SIX .1172 DIA HOLES EQUAL
ON 1.062 DIA BC (REF

GIR

1. MANUFACTURE
2. BENDIX CORP
3. EMPTY TANK
4. 186 - 196
5. OPERATING A
6. A MAXIMUM OF
7. B PROOF PRES
8. C. BURET PRE
9. 10. PERFORMANCE
10. A SERVICE
11. B. MAXIMUM I
12. 9 THIS UNIT SH
13. PROTECTED A
14. COMPATIBLE
15. OF ANY TONE
16. 8 PROTECTIVE C
17. PNEUMATIC C
18. BE REMOVED
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21. RESEARCH
22. 5 THIS UNIT IS
23. SPEC C-28
24. CAUTION THI
25. HOLE ONLY. L

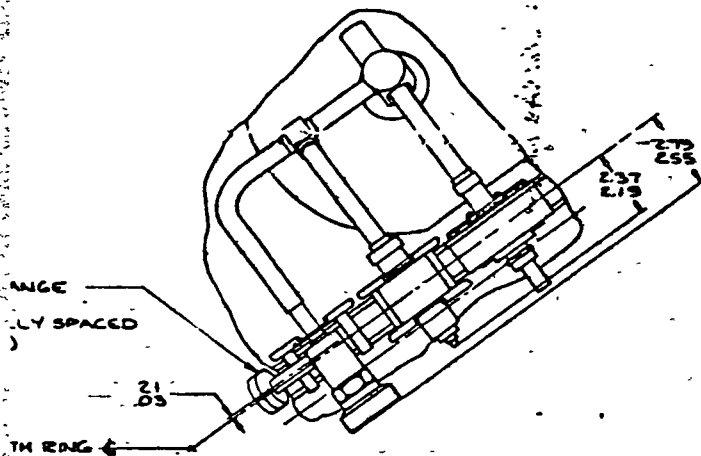
1. CONTAINER TO
2. TO GRAVITY
3. 2 PRIOR TO SHIP
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REV	BY	DATE	DESCRIPTION
1	1	1	1

REVISION 5



VIEW FF
(851240-2-1 ONLY)

D BY ELECTRICAL COMPONENTS DIV. OF

SIDNEY, N.Y.

CAPACITANCE VALUE SHALL BE

1000-PFARADS AT 70°K.

REQUIREMENTS:

SEATING PRESSURE 320 PSIG MAX AT 200°R

SURE: 480 PSIG MAX AT 200°R

SSURE: 640 PSIG MAX AT 200°R

RE REQUIREMENTS:

HYDROGEN

INTERNAL OPERATING TEMPERATURE 200°R

ALL BE OF CORROSION RESISTANT MATERIALS OR SUITABLY

GAINST CORROSION MATERIALS & FINISHES TO BE

WITH HYDROGEN SUCH THAT THEY PRECLUDE THE GENERATION

PRODUCTS IN A 100% PURE HYDROGEN ATMOSPHERE.

EVER'S PROVIDED AT ALL ELECTRICAL &

CUSTOMER CONNECTING POINTS, ARE TO

AT TIME OF UNIT INSTALLATION ONLY.

DIAGRAM SEE DRAWING NO 956037

REFORMS TO THE REQUIREMENTS OF

SPEC 68-3635

PACKAGED FOR SHIPMENT PER AIRSEARCH

3 UNIT TO BE LIFTED BY .260-.266 DIA(REF)

DO NOT USE MOUNTING POINTS

BE ORIENTED AS SHOWN WITH RESPECT

FOR FILLING

MENT THIS UNIT WAS PROCESSED IN ACCORDANCE

EN PROCESS SPEC C-38, CLASS I, FOR USE

EN SYSTEM

IVEN ARE FOR INSTALLATION PURPOSES ONLY

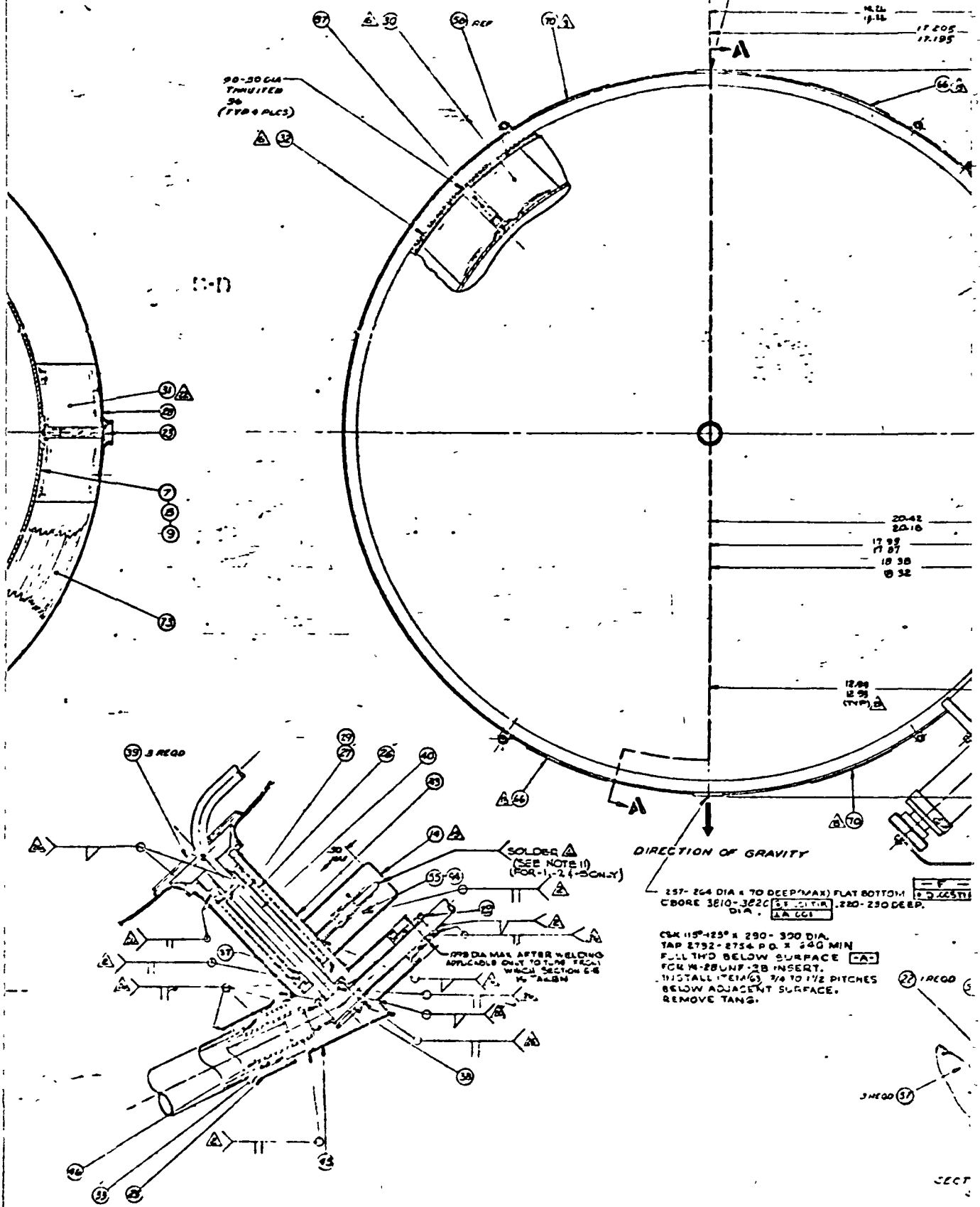
UNLESS OTHERWISE SPECIFIED

851240-2-1	956043-23	SAME AS 851240-12 EXCEPT PER VIEW FF 1 WITHOUT ANNUAL INSULATION
851240-12	956043-15	851240-12 EXCEPT WITH SOLID DIELECTRIC RING
851240-10	956043-1	AS 3-2-1
PART NO	ASSEMBLY NO	REMARKS
QTY	ITEM NO	CODE
NO	IDENT NO	IDENT NO
NOMENCLATURE OR DESCRIPTION		
PARTS LIST		
AIRSEARCH MANUFACTURING COMPANY		
TANK OUTLINE, HYDROGEN SUPERCRITICAL		
1	70210	851240
SCALE 1/2		
SHEET 1 OF 1		

CTYP 2 PLACES



POD-SUP FRAME 2



257-264 DIA TO TOP/VALVE FLAT
CORE 30" 3020-3025 TYP
DIA 1.5 1.5
CSK 115°-125° X 290-300 DIA
TAP 2732-2754 P.D. X 640 MIN
FULL THD BELOW SURFACE
FOR W-28 UNF-38 INSERT.
INSTALL ITEM 53 1/4 TO 1/2 PITCH
ADJACENT SURFACE
REMOVE TANG.

17.205
17.195

20.42
20.16
17.99
17.97
18.38
18.32

12.44
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(TYP)

DIRECTION OF GRAVITY

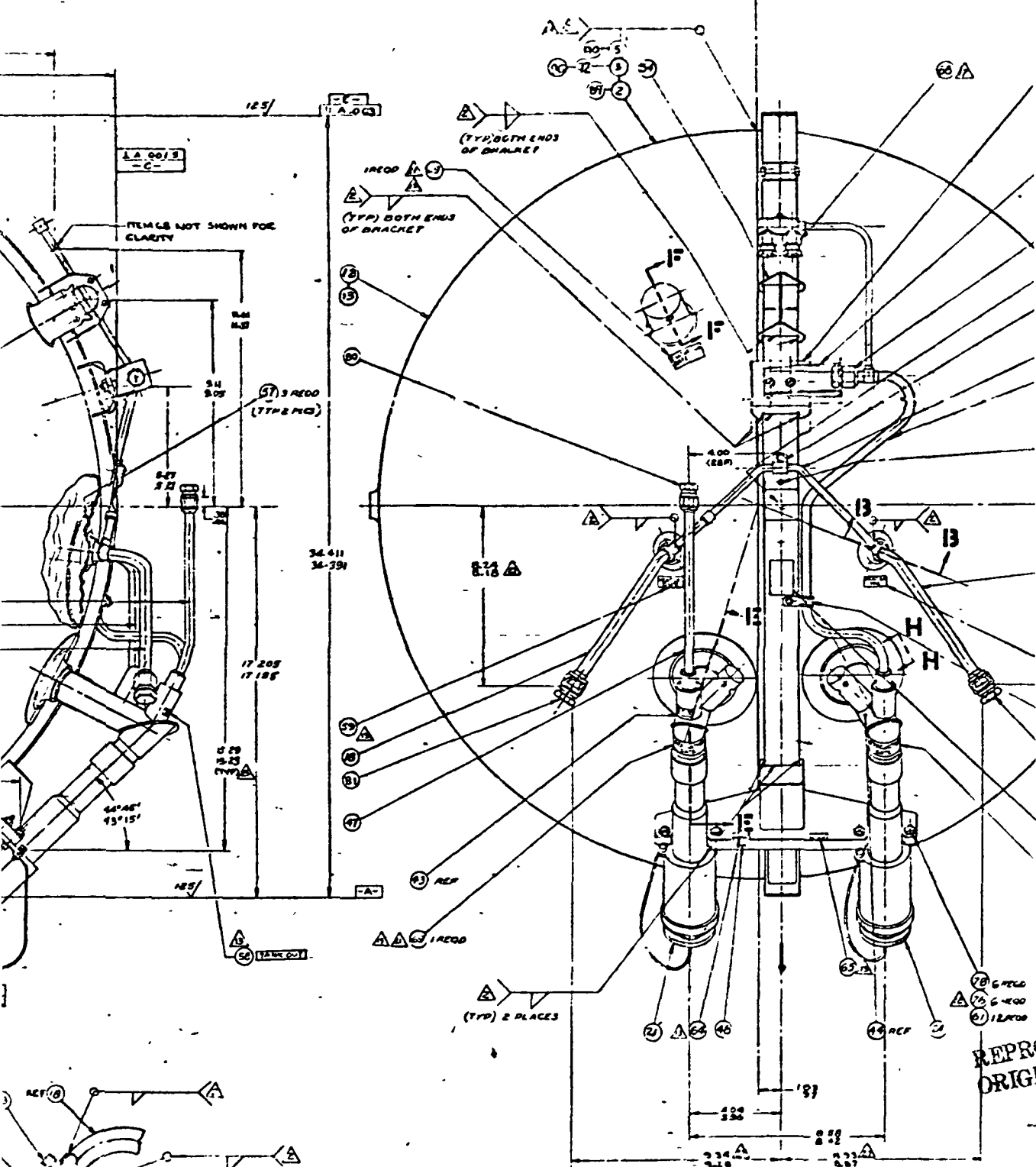
257-264 DIA X 70 DEEP (MAX) FLAT BOTTOM
CORE 3810-3820 3815 DIA 1.220-230 DEEP
DIA 1.5 1.5

CSK 115°-125° X 290-300 DIA
TAP 2732-2754 P.D. X 640 MIN
FULL THD BELOW SURFACE
FOR W-28 UNF-38 INSERT.
INSTALL ITEM 53 1/4 TO 1/2 PITCHES
BELOW ADJACENT SURFACE.
REMOVE TANG.

SECTION E-E
SCALE 1/1
(TYPICAL PLACES EXCEPT AS SHOWN IN SECTION H-H)

5- FOR
5 BELOW

FOLDOUT FRAME 3



ION 13-13 (TYPE 2 PULSES)
SCALE 4/1

- a. 2009 DIMENSIONAL EXPANSIONS ARE TO ESTABLISH CENTERLINE LOCATION OF ITEM AND DO NOT NECESSARILY GO TO EDGE WITH END OF JOINT
- b. AED TRANSFER FROM 15' TO 30' DIMENSION
- c. DIMENSIONS ARE APPLICABLE TO ITEM AS SHOWN AND ARE TO CENTERLINE OF CUMULATIVE MOUNTING HOLE PATTERNS ON SURFACE TO WHICH ITEMS ARE MOUNTED
- d. LOCAL EXTENSION DIMENSIONS OF THE SHELL SURFACE ADJACENT TO THE GIRTH ARE AN ACCEPTABLE APPROXIMATION THAT THE AREA OF THE EXPANSION DOES NOT EXCEED 5 SQUARE FEET, 20% HEIGHT, OR 200 FEET GIRTH. IF THESE EXPANSIONS MUST BE SMOOTH CURVED SURFACES

[illegible]

REPR
ORIG

591005